Evaluation of selected legumes for sustainable weed ecology/soil fertility/livestock management interactions in crop-livestock systems of the moist savannah of Nigeria

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Declaration

I, the undersigned, declare that the work in this dissertation contains my own original work that has never before been submitted as a whole or in part at any other University for the purpose of acquiring a degree.

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Signature:. Date:..

Abstract

This project aimed at enhancing the net benefit in production systems. It took a holistic approach to evaluate the potential interactions of herbaceous legumes in relation to weed dynamics, soil fertility and livestock management in the crop-livestock system in Nigeria. The project was carried out between 2000 and 2002 in two localities. These were the National Animal Production Research Institute (NAPRI) at Zaria in the northern Guinea savannah and the International Institute of Tropical Agriculture (IITA) at Ibadan in the derived savannah. The main experiment was carried out in the northern Guinea savannah, while the secondary experiments were simultaneously conducted in the derived savannah and the northern Guinea savannah. The experimental design for the three experiments reported in this thesis is a split-split plot, fitted into randomised complete block design (RCBD), with four replications. Main plot treatments were herbaceous legumes, namely *Vigna unguiculata*, *Arachis hypogaea, Glycine max*, *Aeschynomene histrix, Centrosema pascuorum, Stylosanthes guianensis* and natural vegetation. Sub-plot treatments were management systems (1) *M1*, 'residues left in the field'; (2) *M2*, 'residues taken out of the field' and (3) *M3*, 'residues fed to livestock, manure/urine/refused feeds returned'. Sub-plot treatments were administered in a sequence following rotational fallows of herbaceous legumes and natural vegetation. However, plots in the secondary experiments were not subdivided before the cropping of maize in 2002, and for logistical reasons only two sub-plot treatments, *M1* and *M2*, are featured in this experiment.

Herbaceous legumes were established at the start of the rainy season, approximately in June, in 2000, 2001 and 2002. All herbaceous legumes received single super phosphate (SSP) at 20kg ha^{-1} P_2O_5 at planting, while minimum hand weeding was done to maintain pure legume stands during the establishment phase. Forage biomass was higher in the derived savannah than in the northern Guinea savannah. Similarly, higher forage yields were observed after two consecutive years of legume fallow and natural vegetation, compared to the first year plots. Grain yield for *Glycine max* was consistently higher than for the other two grain legumes in 2001 and 2002.

Chemical analysis of herbaceous legumes and natural vegetation showed that crude protein values ranged between 11.2% to 17.3% for legumes; that was significantly ($p<0.05$) higher than the 8.6% value found for natural vegetation. Moreover, all herbaceous legumes and natural vegetation, except *Arachis hypogaea*, had dry matter digestibility values of more than 30%.

Maize grain and stover yields on herbaceous legumes fallowed plots were evaluated and compared with those for natural vegetation. Results in 2001, i.e. after a one-year fallow with legumes, indicated that the dry matter of maize grain and stover yields in the *Stylosanthes guianensis* plots were higher among the forage legumes. *Arachis hypogaea* gave the highest grain and stover yields among the grain legumes in the northern Guinea savannah. Results in 2002, i.e. after a two-year fallow, also showed that the productivity of maize planted on *Arachis hypogaea* and *Glycine max* fallowed plots were consistently higher across the three management systems tested in the northern Guinea savannah. At Ibadan, plots fallowed with *Centrosema pascuorum* and *Aeschynomene histrix*, under management system *M2,* gave the best maize grain and stover yields.

The dynamics of weed distribution and composition were monitored throughout the experimental period. Soil seed bank studies were carried out on soils fallowed for one-year and compared with the initial soil seed bank. Weed infestation showed a consistently higher biomass on natural vegetation plots, than on the herbaceous legumes plots. Their performance in terms of weed suppression was in the order of *Stylosanthes guianensis, Centrosema pascuorum, Vigna unguiculata, Glycine max, Arachis hypogaea,* and *Aeschynomene histrix*. Dominant weed species on experimental plots were *Eleusine indica, Celosia trigyna, Dactygloctenium aegyptium, Ageratum conysoides, Eragrostis turgid, Stylochiton species, Borreria stachydea, Tridax procumbent,* Sedges, *Starchytapheta augustifolia, Euphorbia heterophylla and Mitracarpus villosus.* The weed seed bank studies also indicated that sedges, *Oldenlandia corymbosa* and *Ageratum conysoides* dominated the weed seed bank.

The legumes and natural vegetation residues were subsequently fed to rams to generate compost for subsequent cropping. A detailed feeding trial was conducted to determine the growth of the rams and the digestibility of the feed over a 56-day feeding period. Rams fed *Arachis hypogaea* gained 85.7g day^{-1}, followed in decreasing order by those fed *Stylosanthes guianensis*, *Centrosema pascuorum*, *Glycine max*, *Aeschynomene histrix*, *Vigna unguiculata* and least weight gain was recorded for the natural vegetation.

Objective functions in linear optimisation, or linear combinations in algebra, used to link dynamic processes in livestock production (liveweight gain) with the dynamic processes in soils (soil nitrogen), weeds (weed biomass), herbaceous legumes (legume biomass) and crop production (maize grain and stover yields) under varying management systems took the form:

Management system 1, $Y_1 = f\ (x_1, x_2, x_4);\ Y_2 = 0$ **(1)**

Management system 2, $Y_1 = f\ (x_1, x_2);\ Y_2 = 0$ **(2)**

Management system 3, $Y_1 = f\ (x_1, x_2, x_3);\ Y_2 = f\ (x_1, x_2, x_4, x_5)$ **(3)**

Where

Y_1 = Crop in kg; Y_2 = Livestock weight gain in kg; X_1 = Weed in kg; X_2 = Soil N g kg^{-1}; X_3 = Livestock compost in kg; X_4 = Herbaceous legumes in kg; X_5 = Maize stover in kg, for the three management systems considered in this experiment.

Deductions from these equations showed that *Aeschynomene histrix* performed better under *M1*, i.e. when legumes residues were left on the field. Natural vegetation performed better than the herbaceous legumes under *M2*, i.e. when legumes residues were exported out of the field. However, the presence of manure in *M3* enhanced soil fertility in the system and improved the overall productivity across all the legumes and natural vegetation.

Overall rankings, conducted by pooling all components in the system, indicated that *Glycine max* performed best among the legumes, followed by *Stylosanthes guianensis* and *Arachis hypogaea*, which ranked second and third respectively. In relation to the specific legume groups, *Stylosanthes guianensis* performed better than the other two forage legumes, while *Glycine max* also performed better than the other two grain legumes tested.

We can see from these on-station research results that there are indications of positive opportunities for improving overall productivity and resources. This can be done through integrating and complementing crop and livestock production, to provide a sustainable intensification of agriculture.

Uittreksel

Die studie is uitgevoer om die potensiële wisselwerking van kruidagtige peulplante met onkruiddinamika, grondvrugbaarheid en veebestuur te evalueer. Die hoofeksperiment in die "Northern Guinea Savannah" is vanaf 2000 tot 2002 uitgevoer by die "National Animal Production Research Institute" (NAPRI) in Zaria, Nigerië. Die twee sekondêre eksperimente is gelyktydig in Zaria en by die "International Institute of Tropical Agriculture" (IITA) naby Ibadan in die "Derived Savannah" uitgevoer.

Die eksperimentele ontwerp was 'n dubbel gesplete perseel ontwerp gepas in 'n volledig ewekansige blokontwerp met vier herhalings. Die hoofkomponente was die kruidagtige peulplante naamlik: *Vigna unguiculata*, *Arachis hypogaea, Glycine max*, *Aeschynomene histrix, Centrosema pascuorum, Stylosanthes guianensis* en natuurlike plantegroei. Die gekose peulplante is potensieel aangepas vir uiteenlopende omgewings en word dikwels na verwys as '"n mandjie van opsies". Subperseel behandelings was (1) peulplant gevestig en gelaat op die land - *M1*; (2) peulplant gevestig, geoes en weggeneem uit die land - *M2* en (3) peulplant gevestig, geoes, vir vee gevoer, mis/urine/vermorste voer terug na die land - *M3*. Die dubbel gesplete perseel behandelings is toegedien in 'n sekere volgorde nadat die peulplant rusoes/braak toegepas is. In die eerste jaar is die kruidagtige peulplante geplant op die hoofperseel van 25m by 50m. In die tweede jaar is die hoofperseel verdeel in twee persele waar onderskeidelik peulplante en mielies gevestig is terwyl daar in die derde jaar 'n verdere verdeling was wat gelei het

tot verskillende gewasrotasiestelsels, nl. Peulplant-peulplant-mielies, peulplant-mielies-peulplant en peulplant-mielies-mielies.

Parameters wat insluit planthoogte, -wydte en persentasie grondbedekking van die kruidagtige peulplante is tweeweekliks gemeet op vier 1*M2* persele wat ewekansig oor elke hoofperseel versprei is in beide gebiede waar die studie uitgevoer is.

Resultate het getoon dat die kruidagtige peulplante wat getoets is potensiële kandidate is vir insluitings in gewas/weiding rotasiestelsels. Alhoewel voerproduksie hoër was in die "derived savannah" as in die "northern Guinea savannah", het die prestasie van die peulplante in die noordelike savannah gevarieer met die gewasproduksiestelsels. Hoër opbrengste is gerealiseer na twee opeenvolgende jare van oesrus met peulplante vergeleke met die eerste jaar waar daar geen residuele effek van die peulplante was nie, en die laaste jaar wat deur 'n mielie-oes voorafgegaan is. Biomassa opbrengste na twee jaar van aanhoudende verbouiing was die hoogste vir *S. guianensis* en die laagste vir *A. hypogea*. Ruproteien inhoud van die kruidagtige peulplante het gewissel van 170 g kg^{-1} DM in *A. hypogea* tot 62.4 g kg^{-1} DM in *A histrix*. Graanproduksie deur *G. max* was deurlopend hoër in 2001 en 2002 vergeleke met die twee ander graanproduserende peulplante nl. *V. unguiculata* en *A. hypogea*. Die voerproduksie in 2002 was heelwat hoër as die vorige jaar.

Rotasie effekte op mieliegraan en oesreste na peulplante is vergelyk oor die dubbel gesplete persele (areas met verskillende oesruslengtes) om die implikasies van hulle residuele effek op grondvrugbaarheid verbetering en onkruid dinamika te bepaal.

Mielie-opbrengs na een jaar van rusoes toon hoër waardes op persele wat onder kruidagtige peulplante was vergeleke met natuurlike plantegroei. Net so was die opbrengs deurlopend hoër op persele waar daar graan peulplante was as waar daar voer peulplante was. Oor die algemeen was die waardes hoër vir *G. max*, gevolg deur *A. hypogea, A. histrix, C. pascuorum, V. unguiculata, S. guianensis* en die laagste vir natuurlike plantegroei. In terme van die bestuurstelsels, het persele wat kompos ontvang het (*M3*) beter as die ander twee bestuurstelsels presteer (2.6 Mg ha^{-1} mieliegraan). Produksie van mieliegraan en oesreste na twee opeenvolgende jare van mielieverbouing was die hoogste na *G. max* (7.2 Mg ha^{-1} mieliegraan), gevolg deur die *A. histrix* perseel en die laagste op *S. guianensis* persele. Algemene waarnemings oor die twee subpersele wat met mielies beplant was in 2002 het getoon dat mielies beter presteer het op persele wat twee opeenvolgende jare met peulplante beplant was.

Onkruidsamestelling en verspreiding is in beide die peulplante en natuurlike plantegroei gemeet. Grond vir saadbankontledings is op diagonale transekte in 0.5m by 0.5m kwadrate gemonster. Grondmonsters is ge-analiseer vir pH, totale stikstof, organiese koolstof, fosfor, kalsium en magnesium. Hierdie parameters is gebruik in 'n meervoudige regressie ontleding om hulle effek op onkruidspesievoorkoms te bepaal.

Onkruidgetalle in lande na 'n rusoes het 'n deurlopende hoër vlak van besmetting getoon op die natuurlike plantegroei persele as op die peulplant persele. Die prestasie in terme van onkruidonderdrukking was in dalende volgorde: *S. guianensis, C. pascuorum, V. ungucuilata, G. max, A. hypogaea* en *A. histrix*. Die onkruidsamestelling het verskil onder die verskillende behandelings en dit het ook met tyd verander in dieselfde behandelings.

'n Bykomende eksperiment met die peulplante is uitgevoer om hulle effek op inname en groei van skape, asook die effek op kompos wat gemaak is van vermorste materiaal en uitskeidings van die skape, te bepaal.

Droë materiaal verteerbaarheid was hoog vir *S guianensis, G. max* en *A. histrix* terwyl die laagste syfer verkry is by *A. hypogea* (177.6 g kg^{-1} DM). Ramme wat met kruidagtige peulplante gevoer is het beter presteer as die wat met natuurlike plantegroei gevoer is. Ramme wat met *A. hypogaea* gevoer is, het 'n gemiddelde daaglikse toename (GDT) getoon van 85.7 g dag^{-1}, gevolg deur *S. guianensis*, *C. pascuorum*, *G. max*, *A. histrix*, *V. unguiculata* en laaste natuurlike plantegroei.

Bykomende ontledings was gemik daarop om objektiewe funksies af te lei om dinamiese prosesse in vee (massatoename) met dinamiese prosesse in grond (grond N), onkruid (onkruidmassa), kruidagtige peulplante (peulplantmassa) en mielies (mieliegraan en oesreste massas) onder verskillende bestuurstelsels te verbind. In 'n poging om objektiewe funksies van die verskillende komponente van die studie te bepaal, is die volgende lineêre funksies vir die drie bestuurstelsels oorweeg nl.

Bestuurstelsel 1, $Y_1 = f(x_1, x_2, x_4)$; $Y_2 = 0$ (1)

Bestuurstelsel 2, $Y_1 = f(x_1, x_2)$; $Y_2 = 0$ (2)

Bestuurstelsel 3, $Y_1 = f(x_1, x_2, x_3)$; $Y_2 = f(x_1, x_2, x_4, x_5)$ (3)

Waar

Y_1 = Oesopbrengs in kg; Y_2 = Daaglikse massatoename in kg; X_1 = Onkruidmassa in kg; X_2 = Grond N in g kg^{-1}; X_3 = Kompos in kg; X_4 = Kruidagtige peulplante in kg; X_5 = Mieliereste in kg.

Onder bestuurstelsel 1, het *A. histrix* beter as die ander gewasse presteer, terwyl natuurlike veld beter presteer het onder bestuurstelsel 2. Dit is 'n aanduiding dat bestuurstelsel 2 nie volhoubaar is nie. Die derde bestuurstelsel verteenwoordig volle integrasie van gewas en vee produksiestelsels. Die teenwoordigheid van mis in die stelsel het grondvrugbaarheid verbeter en algemene produktiwiteit verbeter.

Hierdie resultate dui aan dat daar geleenthede is om algemene produktiwiteit te verbeter deur integrasie en komplementering van gewas- en veeproduksiestelsels om volhoubare intensifikasie van landbou te bereik.

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Dedication

... the stone which the builders rejected the same is become the head of the corner: this is the Lord's doing and it is marvellous in my eyes**...**

Mathew 21^{42}

You maketh impossibility to be possible. You raiseth the poor from the dust. Alpha and Omega. The beginning and the end, God mighty in battle, Shepherd of my soul, I thank you Jehovah Jare for what you have done.

Owoeye, Lawrence G.

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Chapter 1

Problem statement and research topics

1.1 Introduction

Global food production per capita has increased by 15% in the past decade, while the world population has increased by 45% (Berrett, 1999). By 2050, the developing world's population is projected to grow to 7.6 billion; with 20% in East Asia (EA), 29% in South Asia (SA), 10% in South-East Asia (SEA), 10% in Central and South America (CSA), 20% in Sub-Saharan Africa (SSA), 9% in West Asia–North Africa (WANA) and 1% in Newly Independent States (NIS) (FAO 1998; Thornton *et al.*, 2002). These changes will lead to rapidly increasing demands for food and livestock production.

The lowland moist savannah of West Africa where this study was carried out was classified on the basis of the length of the growing period (LGP) per annum, which ranges between 151 and 270 days. The region is divided into three regions, the northern Guinea savannah, with a LGP of 151 to 180 days, the southern Guinea savannah with 181 to 210 days and the derived savannah with 211 to 270 days (Jagtap & Amissah-Arthur, 1999). Coincidentally, these strata are well-represented in Nigeria.

Traditional land-use patterns in the region show a relatively higher importance of livestock husbandry in the drier north, than in the more humid south, where arable farming dominates. At the same time, intensive arable farming systems also exist in drier regions, in close proximity to extensive livestock production systems (Muhr, *et al.,* 1999). As more and more rangelands are converted into cropland, there is increasing pressure on the resource base; farmers can no longer practice existing shifting cultivation, while herders complain of feed shortages. The resulting effect of this scenario leads to land degradation.

However, there are opportunities for the simultaneous use of the available land for both crops and forage plants, through the use of dual-purpose crops and integration of multipurpose species. If properly managed, such approaches/interventions could lead to better integration of crop-livestock production. For instance, the exchange of grain, crop residues and water for manure and milk is a usual practice (Jagtap & Amissah-Arthur, 1999). These enterprises, however, provide ample opportunities for improving overall productivity and resources, through integration and complementing crop and livestock production, to provide opportunities for sustainable intensification of agriculture (Tarawali *et al.*, 2001).

The system is further enhanced when herbaceous legume crops are included in the system (Tarawali, 1994). Past research on the interactions of herbaceous legumes in a crop-livestock system was centered on specific aspects of the system. However, there were few attempts to take a holistic approach to study the interactions of weed dynamics, soil fertility and livestock management, as outlined in this study (Reese, *et al.,* 1987; Robeldo, Correal & Rios, 1989; Tarawali, 1994; Tarawali & Peters, 1996). It is therefore apparent that appropriate research is needed to make sure that the potential benefits of incorporating herbaceous legumes are optimised, while minimising any detrimental effects. In the present study therefore, three management approaches (Fig. 1.1) with herbaceous legumes were proposed, to evaluate weed dynamics, soil fertility, and to address the quantitative and qualitative seasonal feed shortages faced by ruminants.

1.2. Objectives of this study

The overall objective was to evaluate the potential interactions of herbaceous legumes in relation to weed dynamics, soil fertility and livestock management in a crop-livestock system.

1.2.1 Priority activities and specific objectives

This study was designed to address the overall objective of the project through the following activities:

1 Agronomic evaluation of herbaceous legumes with respect to restoration of soil fertility, weed management, and crop-livestock sustenance

- to investigate the effect of removal/retention of herbaceous legume biomass on weed dynamics, soil fertility and crop yield.
- to investigate the effect of returning manure from livestock fed with herbaceous legume biomass on weed dynamics, soil fertility and crop yield.

2 Livestock feeding with herbaceous legumes.

- to assess feed quality for prediction of potential live weight changes of small ruminants fed on herbaceous legume residues.
- to evaluate the quantity and quality of total manure, urine and refused feeds generated by small ruminants fed on herbaceous legume residues.

3 To develop recommendations for the appropriate management of herbaceous legumes to maximise contributions to crop and livestock productivity.

1.2.2 Hypotheses

The following hypotheses were considered during the course of the experiment:

- herbaceous legumes grown in rotation with crops do not influence weed dynamics in the crop production systems.
- herbaceous legumes grown in rotation with crops do not influence the fertility of the soils within the crop production systems.
- herbaceous legumes grown in rotation with crops do not influence the yield of crops within the crop production systems.
- herbaceous legumes fed to small ruminants do not influence the average daily gain of the animals.

- refused feeds/manure/urine returned to the field do not influence soil fertility and crop yield.

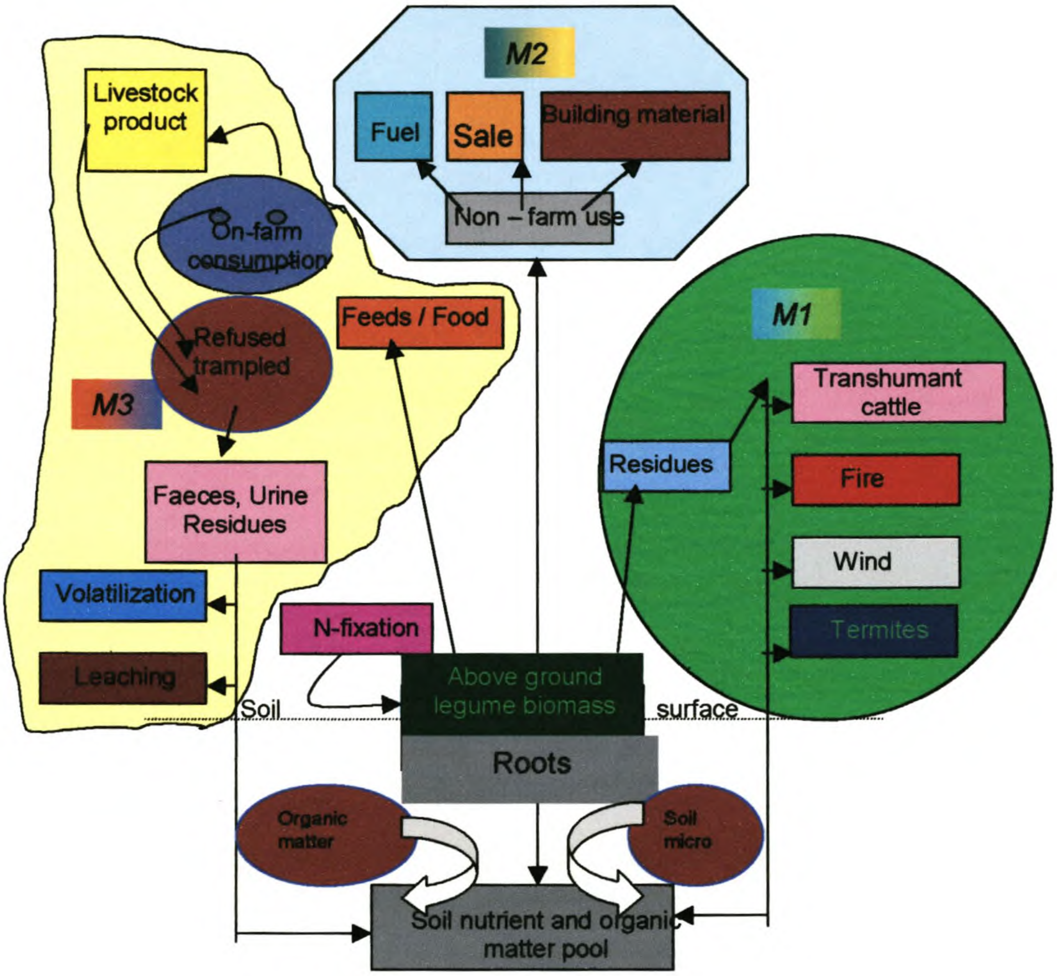

Figure 1.1 Schematic presentation of synergetic interactions between potential biomass and nutrient losses in a legume-based system.

M1= legume planted, left in the field
M2= legume planted, harvested and exported out of the field
M3= legume planted, harvested and fed to livestock, manure/urine/refused feeds returned

1.3 Thesis outline

Previous research recommended the inclusion of legumes to reduce the effects of *Striga* spp. by improving soil fertility and provision of feeds for livestock, especially during the dry season (Tarawali, Peters & Schulze-Kraft, 1999). The present project aimed at a multi-faceted approach with herbaceous legumes to address salient issues relating to the integration and reciprocal benefits of introducing herbaceous legumes for weed control, soil fertility improvement and livestock management. It is worth noting that a wide variety of separate crop and livestock models exist, but the nature of crop-livestock interactions, and their importance in smallholder farming systems, makes their modelling difficult (Thornton & Herrero, 2001).

In an attempt to assess the individual contributions of key components in the study, chapters are divided as follows. The first three chapters present a brief introduction and literature review of all factors, including the selected herbaceous legumes and site locations. Chapters four to seven outline results and discussions on treatment effects and management systems influence on the test crop - *Zea mays*, soil fertility, weed dynamics and livestock management. Chapters eight and nine focused on interactions between these components and general conclusions.

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Chapter 2

Literature review

2.1 The environmental setting

Sub-Saharan Africa (SSA) exhibits considerable diversity in agro-ecology, which results from variations in rainfall, altitude, slope and soils (Jabbar, 1995). Mean annual rainfall ranges from less than 100mm in some areas of the Sahel, to 9000mm in the mountains of Cameroon (FAO, 1985). Altitude ranges from 120m below sea level in the Danakil depression of Ethiopia to 5895m above sea level on the summit of Mount Kilimanjaro. About 4% of the total area is classified as highlands. Soils vary in texture from sandy Aerosols to heavy, poorly drained Vertisols. Acid soils, Ferrasols and Acrisols, cover about 18% of the region, and 10% of these, Solonchaks and Solonetz, are saline. Deficiencies of macronutrients and trace elements are widespread (Thomas & Sumberg, 1995). Similarly, the soils of West Africa are highly weathered and of low inherent fertility. The main soil groups consist of Alfisols, Ultisols, and Oxisols, with smaller areas of Entisols, Vertisols and Inceptisols; there is a large area of Aridisols in the Sahara (FAO, 1985).

The distribution and population growth pattern in the SSA is not expected to stabilise between now and 2050 (Thornton *et al.*, 2002). The increases in human population and urbanisation are intensifying the demand for agricultural commodities, as a result, the traditional balance between people, their habitat and socio-economic systems is fast disappearing (Mohammed-Saleem & Fitzhugh, 1993). Excessive deforestation, land clearing and cultivation are occurring in an attempt to meet rising food demands.

The resource base of SSA is divided into three strata, namely: low-potential areas vulnerable to faster land degradation, high-potential areas for continuous use with relatively low risk of degradation, and protected areas like forests, that are genetic reserves (Mohammed-Saleem & Fisher, 1993). However, resources in many countries are inadequate to support the growing population at the level of existing technologies, therefore rapid population growth has the greatest impact on agricultural resources (Jagtap, 1995).

Vegetation distribution in high temperature regimes is determined to a large extent by rainfall. Consequently, vegetation zones run parallel from north to south and are related to rainfall quantity (Plate 2.1). The tropical rain forest has become modified into: (i) mangrove tidal swamps and marshlands next to the coast, followed by freshwater swamps which extend along river valleys and streams and which are dominated by Raphia Palms (*Raphia* spp.) and Screw Pine (*Pandanus candelabrum);* (ii) rain or moist forest regrowth which retains some characteristics of the multi-storied structure and species diversity of tropical rain forest where it has not been drastically modified, and (iii) the derived savannah, consisting of open bush land, isolated trees and oil palms.

In Nigeria, the lowland moist savannah region[1] has distinct wet (growing) and dry seasons (Tarawali, Peters & Schulze-Kraft, 1999). Total annual rainfall decreases from the south to the north, and the pattern of precipitation changes from bimodal in the derived/coastal savannahs to monomodal in the southern and northern Guinea savannahs (Jagtap, 1995). Agro-climatically, the region is well suited to crop production but the soils, mostly Alfisols, are very poor and often limit agricultural productivity (Jabbar, 1992).

2.2 *Crop-livestock systems*

Traditional farming systems in the SSA showed that crops and livestock have been operationally separated, but functionally linked, enterprises (Powell & Williams, 1993). The exchanges between sedentary crop farmers and migratory pastoralists of grain, crop residues and water for manure have linked crop and livestock productions for years in many regions (Powell, 1986). People, cattle, sheep and goats are distinctly distributed across the five agro-ecological zones of Sub-Saharan Africa (Plate 2.1).

In West Africa, the southern Guinea savannah stands out for its high livestock-per-person ratio and low farming potential. Rangeland vegetation in these regions is of high quality and there is a low incidence of livestock pests and diseases. The survival of pastoralists depends on herd mobility to exploit

[1] Divided into three strata based on the length of the growing period (LGP), namely, the northern Guinea savannah, with a LGP of 151 to 180 days, the southern Guinea savannah with 181 to 210 days and derived savannah with 211 to 270 days.

seasonal water and forage supplies. The interaction between crops and livestock within the zone is limited (Powell & Williams, 1993).

In the northern Guinea savannah, farmers own animals and increasingly, pastoralists are growing crops. Crop residues provide a vital feed source during the six to eight months of the dry season and animal manure enhances soil fertility for crop production (Powell & Williams, 1993).

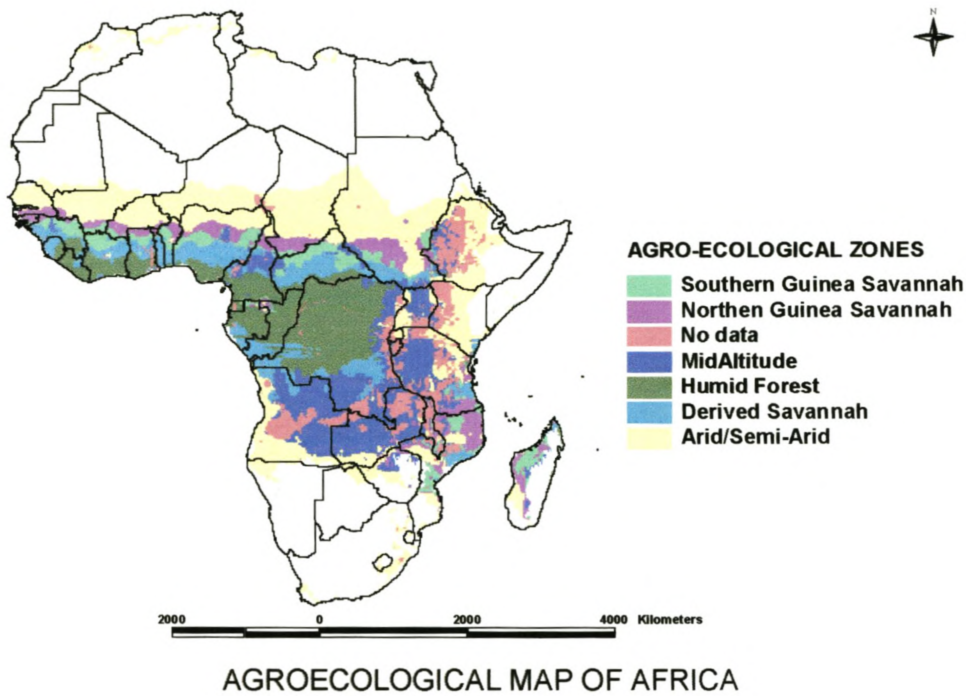

Plate 2.1 Map of Africa showing distribution of savannah.

Source: IITA, GeoSpatial Laboratory, Ibadan.

Pastoralists have traditionally used the derived savannah as a dry season grazing reserve (Winrock, 1992). This zone has the greatest crop diversity. Farmers cultivate a wide range of cereal, legumes, tubers and tree crops in very complex patterns. However, trypanosomiasis and other diseases restrict livestock production in many parts of the zone. The clearing of forested lands for cropping decreases the tsetse threat, thereby making it possible to increase livestock integration in the production system (Jabbar, 1992; Bourn *et al.*, 1994; Powell & Williams, 1993). There is greater potential for crop-livestock integration along the coast due to a large human population. Farmers feed crop residues, sow *forage* crops and recycle manure for soil fertility or fuel (Winrock, 1992).

2.2.1 Livestock production

The sub-humid region of SSA has a cattle population in excess of 37 million head, about 30% of which are found in West Africa (Winrock, 1992). Many of these are nomadic herds, but there is an increasing trend towards sedentarisation (Jabbar, 1992). Cattle are still of importance for former nomadic families that have settled, although herd size often reduces with sedentarisation. The productivity of the cattle is generally poor (Rege, von Kaufmann & Mani, 1993; Rege *et al.*, 1993). Amongst the factors contributing to the low productivity of the cattle herds in Nigeria are low milk offtake, high calf mortality and low fecundity rates; these in turn are related to the low quality and quantity of the feed resources for much of the year (McDowell, 1972; Mohamed-Saleem, 1986).

Current husbandry practices, including daily herd management and late calf weaning, probably designed to cope with the feed constraint, also contribute to the low productivity (Otchere, 1986; Ogunsiji *et al.*, 1988).

Research in the humid and sub-humid regions of Nigeria and elsewhere in West Africa has identified both forage legumes and grasses which may be suitable to supplement forage resources (Tarawali *et al.*, 1999b). Although certain grasses, such as indigenous *Panicum maximum* can give good forage yields, the quality of pasture can be further improved and assured by the inclusion of forage legumes, which retain higher quality throughout the year (Tarawali *et al.*, 1999b).

2.2.2 Evolution of crop-livestock interactions

Powell and Williams (1993) outlined different stages of interactions between crop and livestock enterprises in the process of agricultural and overall economic development. Such stages include pre-intensification phases, where crop production and livestock husbandry are operationally separate enterprises; intensification phases where crop and livestock production integrate mostly through animal draft power and manure linkages; income diversification phases when investments are made to improve forage supply and quality; and a return to specialisation through commercialisation.

As population pressure rises, the demand for arable land increases. Farmers look for alternatives to maintain soil fertility. Both the expanding crop cultivation as a response to the growing food demand, and the immigration of large cattle populations requiring grazing areas, have increased the pressure on land resources in the savannah zone. At these initial agricultural intensification stages, cropping and livestock husbandry remain separate enterprises. Crop farmers make various arrangements with livestock owners to acquire manure. Manuring of cropland is initiated through an exchange of contracts between farmers and pastoralists (Powell & Williams, 1993). However, the point at which integration replaces this exchange depends on farming intensity, transaction costs, costs of other soil amendments (fertilisers) and other benefits derived from the integration.

With the present population pressure, there are increasing demands on the resource base that results in degradation. This scenario presents opportunities for the simultaneous use of the available land for both crops and forage plants that could lead to better integration of crop-livestock production under an improved management system (Tarawali *et al.,* 1999b; Larbi *et al.,* 2002).

Mclintire, Bourzat and Pingali, (1992) pointed out that the most important biological interactions between cropping and livestock in SSA evolved through the use of animal traction and manure in cropping and the feeding of crop residues and other cropland forages to animals. Feeding strategies can include unrestricted grazing, stall-feeding, semi-stall feeding and tethering systems. Cereal stover and other crop residues are vital livestock feeds during the dry season. The competition for crop residues between livestock and soil conservation is most acute. High soil temperatures, wind erosion, and sand blasting of young plants pose severe limitations to crop establishment and production. When left in the field, cereal stover provides a physical barrier to soil movement, allowing soil and organic matter to accumulate and enhance soil chemical properties and crop yield (Bationo & Mokwunye, 1991).

Under crop residue grazing, animals remove greater amounts of biomass and nutrients than they return in the form of manure (Powell & Williams, 1993). This nutrient removal by livestock can be attributed to the spatial distribution of animal movement in the landscape, which is usually concentrated around watering points, resting areas and along paths of animal movement. However, excessive removal of biomass from cropland without adequate replenishment rapidly reduces soil nutrient reserves. As a result, nutrient balances (input minus removal) have become negative for many farming systems in SSA (Powell & Williams, 1993).

2.2.3 Manuring cropland in SSA

The integration of livestock into farming systems has long been appreciated in mixed farming systems in SSA, where farmers continue to rely on organic matter recycling for maintaining soil productivity (Powell & Williams, 1993). There are two principal methods of manuring croplands, i.e. farmers either corral their animals overnight on fields between cropping seasons or manure is gathered from stalls and hand-spread on croplands. Corralling returns both manure and urine to the soil and results in greater crop yields than when only manure is applied (Powell *et al.*, 1998). Corralling requires no labor for manure handling, storage and spreading. Winrock International (1992) opined that the move from extensive livestock management based on grazing, to more intensive stall-feeding, could increase nutrient losses and jeopardise long-term soil productivity, if technologies are not available to capture and recycle the nutrients voided by stationary animals. Since approximately 40 to 60% of the nitrogen excreted by ruminants is in the form of urine, the potential for nutrient loss is greater under stall-feeding if refused feeds are not considered. The presence of refused feed in the system helps to capture urine nutrients before spreading on cropland (Fernandez-Rivera, Midou & Marichatou, 1994). The types and amount of animal-excreted nutrients available for recycling depend upon the types and numbers of animals kept by farmers, animal diet, watering regime, and the spatial and temporal distribution of livestock and their movement in the landscape.

2.2.4 Manuring and soil fertility

The improvement of soil fertility in smallholder farming systems in SSA has been rendered more difficult and complicated over the years, due to increasing scarcity of locally derived nutrient sources and the changing socio-economic environment (Mapfumo *et al.*, 2001). The intensive cropping regimes traditionally used by the farmers for many years depleted soil organic matter, reducing soil fertility and water holding capacity (Mwaja & Masiunas, 1997). To alleviate these problems, alternative production systems that reduce pesticide use and tillage and maintain plant residues are on the increase. Although cattle manure remains the most commonly used organic fertiliser, it has a poor capacity to supply nitrogen and is only available to about 50% of the households in the smallholder farming sector in SSA (Mugwira & Murwira, 1997).

In a survey conducted by Mapfumo *et al.*, (2001) mineral fertiliser and manure were generally given the same ranking as nutrient sources. Leaf litter was considered as another important source of crop nutrients, although it was said to be increasingly unavailable (Mapfumo *et al.*, 2001). Contributors in the survey also mentioned the use of crop residues as a nutrient source. However, some farmers said they normally feed the residues to livestock, with the hope of getting greater manure output. The main factors perceived as limiting soil fertility management were high inorganic fertiliser prices, lack of cash and inadequate animal manure and lack of alternative soil fertility management systems.

2.2.4 The effect of manuring and crop residues on weed ecology

Manure and crop residues affect weeds by reducing the need for tillage, modifying the microclimate environment and releasing inhibitory compounds, by allelopathy. Allelopathy is a form of plant interference, caused by the release of chemicals by the plant into the environment as a defense mechanism, to inhibit growth of other plants in the vicinity (Hofman & Hofmanova, 1971).

Allelochemicals can determine plant community structure (Alsaadawi *et al*., 1990; Chou, 1990). Weed problems are usually greater in disturbed soils than in soils where residues contain compounds that stimulate and/or inhibit the growth and development of other plants (Mwaja & Masiunas, 1997) (cf. section 2.4.1). When manure and crop residues are incorporated into the soil, allelochemicals quickly decompose and are leached away from upper soil levels where seed germinate (Kamara *et al*., 1999). When the residues are left on the soil surface, allelochemicals degrade more slowly, thus suppressing weed growth for a longer period. However, opportunities exist for managing weeds and crop residues to minimise crop losses and maximise weed suppression due to allelopathy (Levitt & Lovett, 1984). Negative effects to the crop can also be avoided by exploiting the stimulatory effects of allelochemicals on the crop, managing allelophathic crops to suppress weeds, or developing allelochemicals as herbicides and growth regulators (Mwaja & Masiunas, 1997).

2.3 The role of legumes

The potential contribution of legume-based technologies to the sustainability of intensified farming systems has been recognised for a long time (Weber, 1996). Trials have shown that leguminous crops can increase soil fertility, reduce soil erosion and compaction (Weber, 1996) or they may suppress weeds (Duke, 1981). Additionally, food legumes can provide high quality protein for human nutrition, while *forage* legumes may improve livestock performance (Skerman, Cameron & Riveros, 1988). Most food legumes have a protein content in grain of

20 to 30% compared to 8 to 12.5% in cereals and 1 to 6% in root and tubers crops. Additionally, most legumes have an increased content of several essential amino acids, such as lysine and methionine, which tend to be deficient in cereals (Weber, 1986). Therefore, legumes complement well with the nutritional characteristics of staples, such as cereals, roots and tubers (Rachie, 1977).

Legumes can be integrated into the existing cropping system as cover crops, live mulch, *forage* or food crops through planted fallow or multiple cropping systems (Kang, 1992). There are several species of tropical legumes, but only a few have been studied and mostly for potential as *forage* crops (Tarawali, Mohamed-Saleem & Von Kaufmann, 1987; Tarawali & Mohamed-Saleem, 1992). Forage and grain legumes have the potential to replenish the land over a shorter fallow period than natural fallow, thereby contributing significantly to the sustainability of such intensive systems, while contributing to livestock production and boosting the total economic returns from the land (Mohammed-Saleem & Fisher, 1993).

2.3.1 Effects of legumes on soil fertility improvement

It is widely recognised that the inclusion of legumes in intensifying cropping systems contributes towards improved soil fertility management (Schulz, Carsky and Tarawali, 1999). Tropical *forage* legumes were shown to maintain soil fertility during a short fallow period (Wilson, Lal & Okigbo, 1982; MacCol, 1990; Tarawali, 1991; Tarawali & Pamo, 1992; Tarawali & Peters, 1996). Systematic introduction and screening of legumes and grasses for forage production and soil regeneration potentials commenced in the 1950's and 1960's in many countries (Kategile, Said & Dzowela, 1987). The International Institute of Tropical Agriculture (IITA) and the International Livestock Research Institute (ILRI) also initiated programs to collect, introduce and screen *forage* plants. Legumes were seen to be crucial in providing high quality feed to replace native pastures and to act as a substitute for extended fallow periods as the primary method to maintain soil fertility (Thomas & Sumberg, 1995).

When pasture legumes were initially introduced in the SSA, their effects on soil fertility were not considered, but became important as the environmental conditions changed. The nitrogen fixed by pasture legumes in the experimental fields amounts to between 45kg and 290kg ha^{-1} annually, with even higher amounts in highland areas (Thomas, 1973). Well-adapted and highly productive grain, forage, and green manure legume species are available for the moist savannah of SSA (Tarawali, 1991; Muhr *et al.*, 1997; Peters, Tarawali & Alkamper, 1997; Schulz, *et al.*, 2001). It is important to note, however, that niches for the introduction of green manure legumes do exist. It was observed that farmers in the northern Nigeria grew green manure species on completely degraded fields where no other crops could profitably be grown and would otherwise have been left fallow (Tarawali *et al.,* 1999a). For this reason, green manure legumes may have an important role to play in rehabilitating otherwise unproductive land. Moreover, where land is not limited, traditional fallow systems may be improved by replacing the natural vegetation with leguminous green manure crops (Schulz, Carsky & Tarawali, 2001).

2.3.2 Effect of legumes on weed management

Weeds are major constraints in the utilisation of both natural and sown pastures. Weed control is therefore an essential part of all crop production systems. Weeds reduce yields by competing with crops for water, nutrients and sunlight. Weeds may also directly reduce profits by hindering harvest operations, lowering crop quality, and producing chemicals that are harmful to crop plants (Levitt & Lovett, 1984). In addition, weeds left uncontrolled may harbour insects and diseases and produce seed or rootstocks that infest the field and affect future crops.

Years of research have shown that good weed control within the first four to six weeks after crops are planted is critical in order to avoid yield reduction from weeds (Levitt & Lovett, 1984). There are many cultural, mechanical and chemical methods of weed control, which are extremely effective if applied at the correct time (Young *et al.*, 1978). Weeding by hand may be most effective but is limited by labour availability. Crop rotation is one of the most effective cultural practices for improving long-term weed control (Young *et al.*, 1978). The success of rotation systems for weed suppression appears to be based on the use of crop sequences that create varying patterns of resource competition, allelopathic interference, soil disturbance and mechanical damage to provide an unstable and frequently inhospitable environment, that prevents the proliferation of a particular weed species. The relative importance and most effective combinations of these weed control tactics and weed-suppressive effects of other related factors, such as manipulation of soil fertility dynamics in rotation sequences, need to be examined (Liebman & Elizabeth, 1993).

Crop rotation aids in controlling weeds by:

1) Allowing rotation of herbicides as well as crops, and
2) Providing the opportunity to plant highly competitive crops, which prevent weed establishment.

Rotation with a densely planted crop with little, if any, chemical input, helps prevent most annual weeds from becoming established and producing seed. Some production systems, which utilise rotation with small seeded legumes or other densely grown perennial grass-legume forage mixtures, are effective in reducing populations of some perennial weeds.

Other practices for effective weed control include:

1. Narrow row spacing (15 inches or less)
2. Proper planting date and seeding rate
3. Use of disease-resistant varieties
4. Insect control
5. Adequate soil fertility
6. Adequate drainage (Liebman & Elizabeth, 1993).

Managing weeds in forages or pastures requires a different approach than managing weeds in row-planted crops. Over 95% of weed control in a vigorous, growing forage crop comes from competition provided by the forage. To keep the forage stand competitive and maintain relatively weed-free forage, however, proper fertilisation, grazing or cutting management and insect control, as well as disease-resistant varieties and selective herbicides are needed (Liebman & Elizabeth, 1993).

If weeds become a problem, they can compete for light, nutrients, water and space, thus influencing crop yield. Unlike most grain or fibre crops from which weeds are separated at harvest, weeds are often harvested along with the forage crop, potentially reducing quality. Reductions in quality may occur in the form of lower protein content and feed digestibility. Although weeds do have some feed value, it may differ among species.

When weeds are present, or persist in spite of good management, herbicides can help improve yield and quality. However, the use of herbicides in SSA, due to unavailability and high cost, is not always possible, making a case for alternative approaches to control weeds (Levitt & Lovett, 1984).

2.3.3 Legumes for human food and livestock feed

Herbaceous legumes have the potential to play a central role in promoting the sustainable linkage of crop and livestock production. Food legumes can produce high quality protein for human nutrition, while *forage* legumes may improve livestock growth, milk, meat and wool production (Rachie, 1977).

Research to introduce alternative forage legumes into rotational mixed farming systems has also been shown to improve sustainability in crop yield (Sabiti & Mugerwa, 1990). Tarawali *et al.* (1999b) confirmed the value of using herbaceous legumes that provide *forage* for livestock in the form of dry season *forage*-banks and produce grain for human consumption. However, at the stage of seed maturation, some lose their leaves and become fibrous, resulting in a decline in their nutritive value. Dried legume crop residues like groundnut stems, cowpea hay, lablab hay, *Stylosanthes* hay and M*ucuna* hay, however, may play a very important role in livestock production (Lakpini *et al.*, 2002). They are often fed as supplements to grass and more often to cereal stover basal feed (Tarawali & Mohammed-Saleem, 1992). During the dry season, when the naturally available feed resources are of very poor quality, herbaceous legumes can produce substantial quantities of better and nutritious *forage* for livestock (Makembe & Ndlovu, 1996; IITA, 1997; Tarawali *et al.*, 1999b). Leguminous plants are useful as supplements in meeting the nitrogen requirements of small ruminants, but some are not edible because they contain toxic substances. Feeding too much of fresh legume forage can precipitate bloat in small ruminants and so are best utilised as supplements to grass/crop residues basal diet (Lakpini *et al.*, 2002).

There is, therefore, little doubt that the inclusion of herbaceous legumes in cropping systems will enhance the net benefit to the production systems of the main agro-ecological zones of Sub Saharan Africa (Muhr *et al.* 1999; Tarawali *et al*. 1999b).

2.4 Weed population dynamics

The weed infestation in a field is defined by three parameters: 1) the number of species present, 2) the density of each species, and 3) the distribution of the species across the field (Hartzler, 2000). While the number of species in a field remains relatively constant from year to year, the latter two factors fluctuate widely in response to environment, cultural practices and weed management tactics. It is the continual changes in weed infestation that make successful weed control such a difficult task to achieve consistently.

Farmers cite weeds and their control as one of the most common limitations on farm productivity, because it requires inordinate amounts of manual labour, which may be scarce. Notable among these weeds in the drier regions that proved very difficult to control are species of *Striga*. *Striga gesnerioides, Striga asiatica* (L.) Kunntze and *Striga hermonthica* (Del) Benth occur across the moist savannah of West Africa. They cause considerable crop yield losses. Their contributions (parasitic effects) to different plant crops are well documented (Berrett, 1999). Yield losses in cereals by *S. asiatica* (L.) Kunntze and *S. hermonthica* (Del) Benth may reach 100% and levels of infestation are frequently so high that continued cereal production becomes impossible and farmers have to abandon these fields in search of less infected areas (Berrett, 1999).

2.4.1 Weed seed bank

The weed seed bank in agricultural fields may consist of many species, but in any given year the infestation may typically be dominated by only a few species (Hartzler, 2000). The species that dominate the infestation are those best adapted to current management systems. As farmers adjust their management program to improve control of the species currently dominating the infestation, they typically create an opportunity for other species in the seed bank to escape control and become part of the current problem.

The significance of seed banks in cultivated soils in relation to weed management has long been recognised (Garcia, 1995). Despite their great economic importance, little is known about seed banks in tropical agricultural soils. Harper (1977) opined that the number of individuals present as dormant propagules generally exceeds the number of growing plants. However, knowledge of the ecology and the physiology of seeds of invasive species is crucial to rational weed control. A clear understanding of seed bank dynamics and of its relationship with the aboveground flora is needed to define management systems aimed at minimising weed problems (Garcia, 1995).

A lack of correspondence between seed bank and weed population has been reported by Garcia (1995) and is perhaps caused by the different nature of the factors operating on seeds in the soil and on the aboveground weed community. The time during which an area was under cultivation may also play an additional role. Reductions in crop yield due to weeds are higher in disturbed rather than undisturbed soil (Roberts & Feast, 1973), but cultivation alone is usually not an effective method to reduce the size of weed seed banks (Dotzenko, Ozkam & Storer, 1969). Persistence of weed seeds in soil means that periodic fallow is a poor method of reducing seed bank size (Branchley & Warington, 1945). However, preventing weeds from producing seed in a specific season may contribute to a lower weed population the following season (Harper, 1977). Therefore, fallow with forage legumes that may suppress weed growth, may result in a lower weed pressure in a subsequent grain crop.

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Chapter 3

Natural environment and field establishment

3.1 Natural environment

3.1.1 Site location - Northern Guinea Savannah

One of the study sites was located at National Animal Production Research Institute (NAPRI), Amadu Bello University (ABU), Zaria, Nigeria (8^0 19'N, 12^0 12'E) in the northern Guinea savannah (NGS) of Nigeria (Plate 3.1). The site was under natural vegetation regrowth for about four years prior to this study.

3.1.1.1 General soil characteristics

The soils at the site in the northern Guinea savannah were derived from gneiss and schist of the basement complex. Kowal and Kassam (1978) described the soil physical characteristics in the upland areas as mainly sandy-loam with some outcrops of ironstone on high grounds. The lowland areas have deep grey-brown sandy loams and clay loams associated with poor drainage. This results in temporary flooding during heavy rainfalls. The soils are generally weakly acidic and low in base exchange capacity and phosphorus (Larbi *et al.*, 2002) (Table 3.1).

Table 3.1 Texture and chemical properties of the soils at 0cm to 10cm depth of the project sites in Zaria and Ibadan.

Locations	pH (H_2O)	Org C	N	P	Sand	Silt	Clay
		← g kg^{-1} →		mg kg^{-1}	← g kg^{-1} →		
Zaria	5.4	8.5	2.2	5.1	730	115	155
Ibadan	6.2	9.1	0.91	7.5	530	327	143

Source: Author's fieldwork.

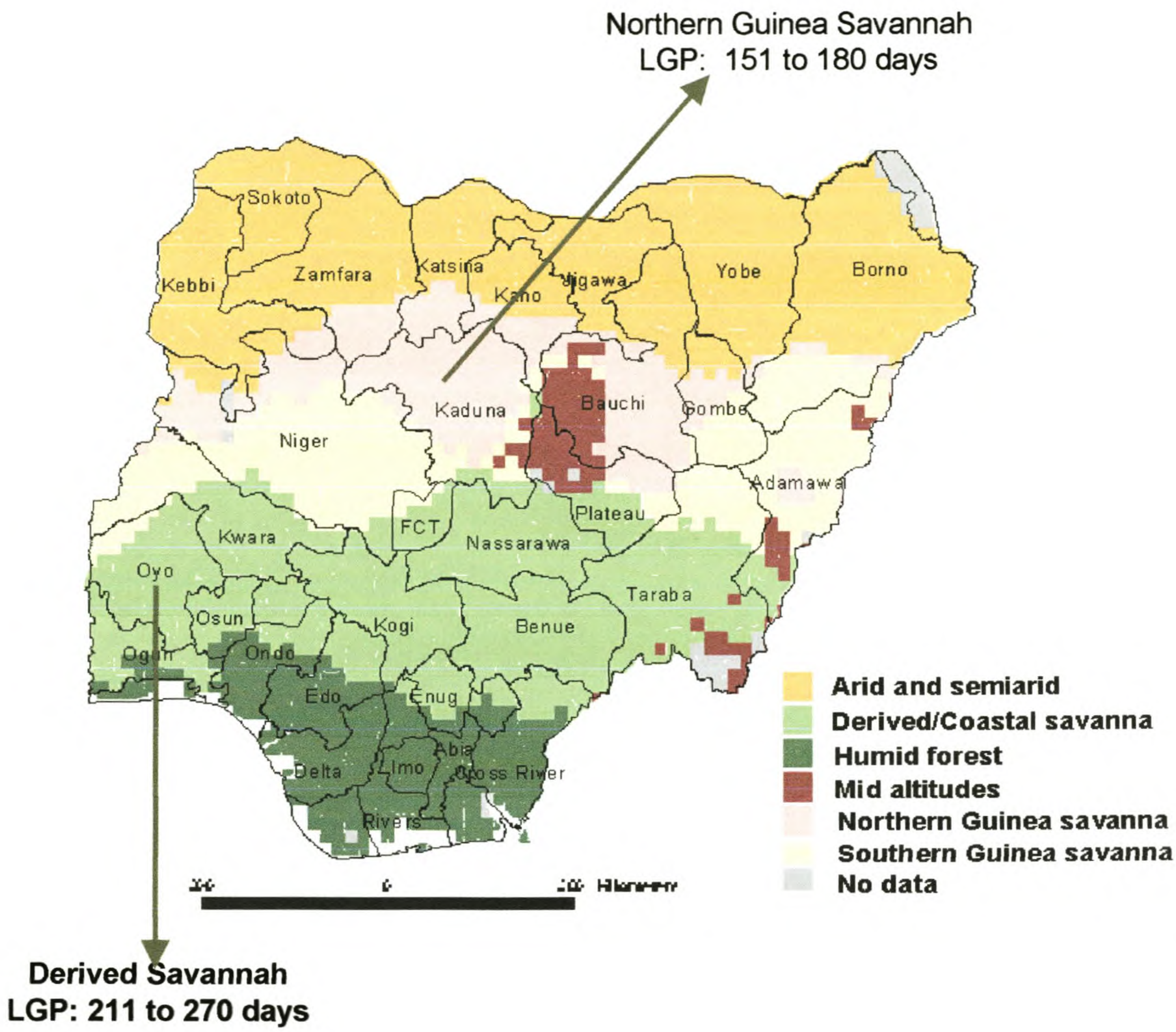

Plate 3.1 Map of Nigeria showing the project sites and vegetation.

Source: IITA, GeoSpatial Laboratory, Ibadan.
LGP = Length of growing period.

3.1.1.2 Climate

The northern Guinea savannah is characterised by a monomodal rainfall of 900-1200mm, which extends over an annual growing period of 150 to180 days. The rain usually starts in May and ends in October, with an average annual rainfall of 1000mm (Jagtap, 1995) (Plate 3.2). Rainfall was higher in 2001 (1322.3mm) than in 2000 (1069.5mm) and 2002 (954.1mm) (Fig. 3.1). The rain was evenly distributed in 2001 and 2002, compared to the rainfall in 2000. The same pattern was observed for average temperature throughout the years of this study. Temperatures were usually higher between March and April, while lower temperatures were observed between December and January (Fig. 3.1). Climatological data collected during the period of this study, 2000 to 2002, are listed in the appendix 2.

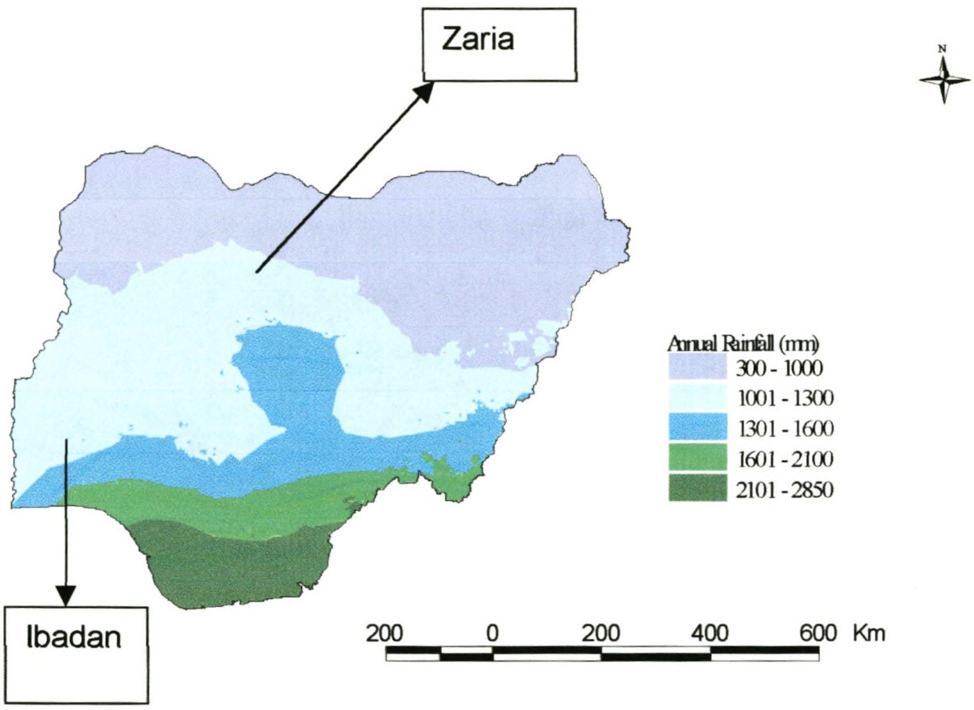

Plate 3.2 Rainfall distribution of Nigeria.

Source: IITA, GeoSpatial Laboratory, Ibadan

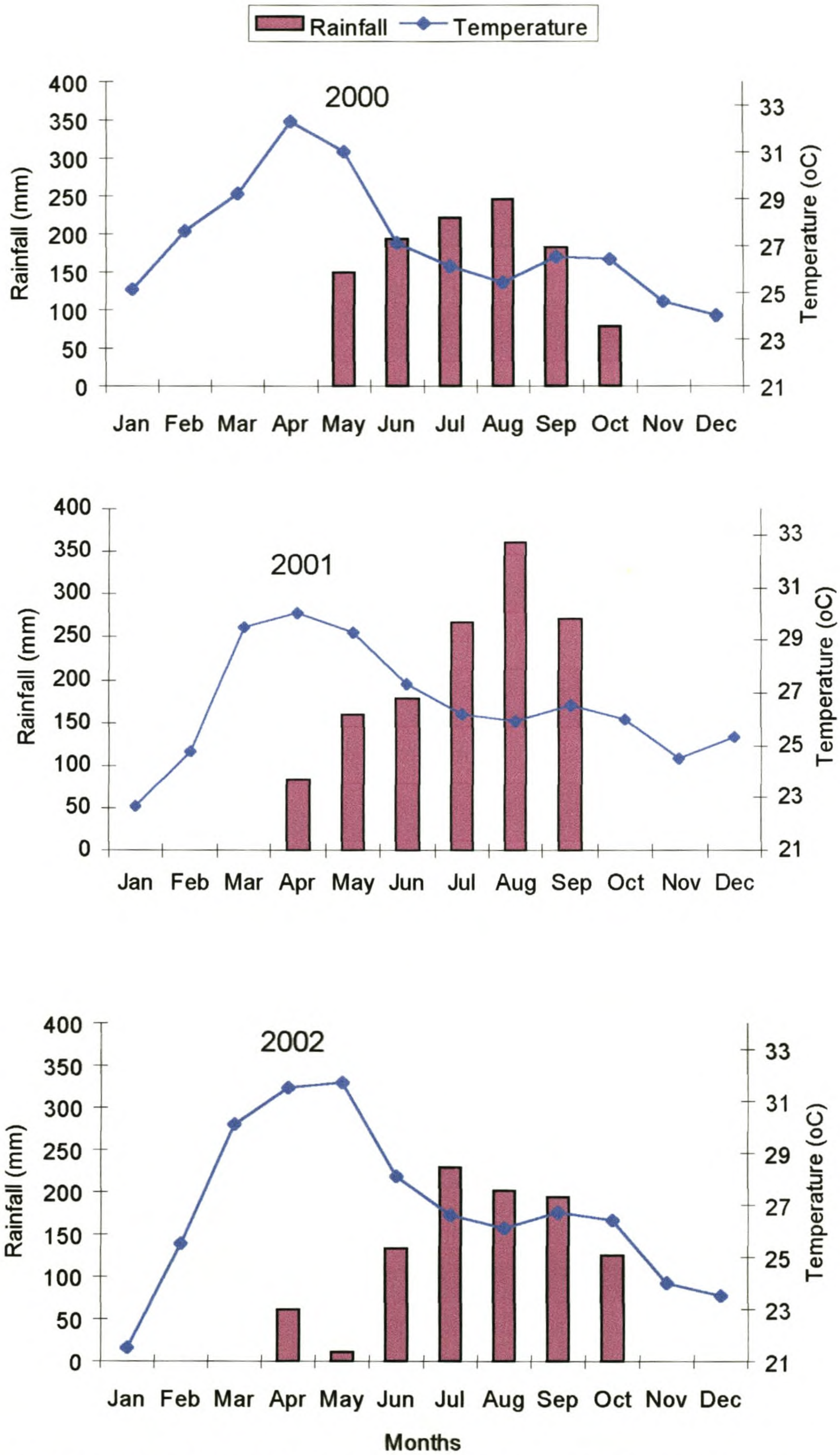

Figure 3.1 Monthly rainfall and mean daily temperature pattern in Zaria during the experimental study.

3.1.1.3 Field establishment of the main experiment

The main experiment was established on plots of 25m by 50m at Zaria in the northern Guinea savannah in 2000. Experimental design was a split-split plot fitted into a randomised complete block design with four replications (Appendix 7). Main plot treatments were six herbaceous legumes and natural vegetation. The selected herbaceous legumes for this study were three forage legumes, *Aeschynomene histrix* accession ILRI 12463 (*A. histrix*), *Centrosema pascuorum* accession ILRI 9857 (*C. pascuorum*), *Stylosanthes guianensis* accession ILRI 15557 (*S. guianensis*) and three dual-purpose grain legumes, *Arachis hypogaea* accession *UGA 5 (A. hypogaea*), *Glycine max* accession TGX 1448–2E (*G. max*) and *Vigna unguiculata* accession T89KD-288 (*V. unguiculata*) and natural vegetation. Criteria for selecting these legumes are further discussed in chapter four (cf. chapter 4, section 4.2 and Table 4.2).

Three management systems capable of reproducing farmers' conditions were considered and fitted into the experimental design as sub-plots. Details of these management systems are depicted in Fig. 1.1 and further discussed in chapter four, section 4.2. The first system, *M1,* represents a smallholder mixed legume-farming system where legumes were planted solely for weed control and soil fertility restoration. Residues generated in the system are applied as mulch. The second system, *M2,* features a smallholder mixed farming system with little or no livestock. Farmers in this system plant legumes and crops, while residues are moved out of the field. The third system, *M3*, presents a situation of a mixed crop-livestock farming system, farmers in this category plant legumes and crops for dual purposes, i.e. for grain and *forage* production and ensure that manure generated as a result of feeding crops residues to livestock is returned to the farmlands.

To achieve this, 50 Yankasa rams, average age of 18 months, mean initial liveweight of 19.5kg, s.e. 2.0, were used to produce manure during the dry seasons in 2001 (April to May) and 2002 (March to April). The herbaceous legumes used as feed were hand-cut at maturity and allowed to dry naturally (cf. chapter 5, section 5.2). In 2001, only herbaceous legumes were fed to rams for manure production. In 2002, feed materials included maize stover grown on the same plot, in addition to the herbaceous legumes. Prior to the start of the feeding experiment, feed materials were chopped into pieces approximately 2cm to 5cm long with a tractor-driven chopper. Rams were grouped according to the amount of feed available (Appendix 1) and fed half of their daily feed ration at 0800 and the remaining half at 1200. Refused feeds were collected and weighed each morning at 0700, while the leftovers were left to be trampled upon by the animal(s) to facilitate mixing with faeces and urine voided by each treatment group. The compost, a combination of refused feeds, faeces, urine and spill over water, was occasionally heaped in a corner of the pen, to simulate farmers' practices.

At the end of the feeding period, which almost coincided with the beginning of the cropping season, the compost produced *in situ* was returned to the exact plot where feed materials were removed. This was incorporated into the soil before the planting of maize. Subsequent planting in 2001 and 2002 featured a division in the main plot to accommodate a split of continuous legume fallow and maize as shown in Table 3.2.

A secondary experiment, intended to complement information on this study across two agro-ecological zones, the northern Guinea savannah and derived savannah, was established at Zaria and Ibadan respectively in 2001. The main treatments were similar, but it was established on smaller plots of 8m by 8m and, due to logistical reasons, the sub-plots had to be decreased. A more detailed description of this experiment is given in section 3.1.2.3.

Table 3.2 The arrangement of sub-plot treatments, showing the rotational planting of herbaceous legumes and the test crop, Zea mays, in the main experiment at Zaria in the northern Guinea savannah.

<table>
<tr><th>Year</th><th colspan="3">Subplot
Treatment (M1)</th><th colspan="3">Subplot
Treatment (M2)</th><th colspan="3">Subplot
Treatment (M3)</th></tr>
<tr><td>2000</td><td colspan="3">HL</td><td colspan="3">HL</td><td colspan="3">HL</td></tr>
<tr><td>2001</td><td>HL</td><td colspan="2">MZ</td><td>HL</td><td colspan="2">MZ</td><td>HL</td><td colspan="2">MZ</td></tr>
<tr><td>2002</td><td>MZ</td><td>MZ</td><td>HL</td><td>MZ</td><td>MZ</td><td>HL</td><td>MZ</td><td>MZ</td><td>HL</td></tr>
</table>

Management simulating farmer's systems are given as
M1= legume planted, left in the field
M2= legume planted, harvested and exported out of the field
M3= legume planted, harvested and fed to livestock, manure/urine/refused feeds returned
HL = herbaceous legumes
MZ = maize, Zea mays Linn.

3.1.2 Site location - derived savannah

The second site was at the International Institute of Tropical Agriculture (IITA) at Ibadan 7^0 30' N and 3^0 54'E, 213m altitude, which is in the derived savannah zone of Nigeria (cf. Plate 3.1).

3.1.2.1 General soil characteristics

The soil at Ibadan is characterised as well-drained clayey upland soil, which has developed from banded gneiss, overlaid by alluvium and biogenetic surface material (Mooremann, Lal & Juo, 1985). It belongs to the group of ferric Luvisols, or Oxic paleustalf, according to FAO (1970). The surface soil texture is a sandy loam overlaying sandy clay or clay subsoil. The experimental site was originally cleared from secondary forest in the mid-1970's and was cultivated continuously until 1996. As a result of long-term continuous cultivation, maize grain yield in the site decreased from an initial >3t ha^{-1} to <1t ha^{-1} in 1989 (Hulugalle, 1992). In association with the soil degradation, the soil organic carbon decreased from 29,400kg ha^{-1} to 21,700kg ha^{-1} (Hulugalle, 1992).

3.1.2.2 Climate

The study site in the derived savannah, Ibadan, has rainfall that ranged between 788 and 1884mm, with a mean of 1282mm, over a period of 20 years (cf. Plate 3.2). The overall length of growing period in the derived savannah was put at between 211 to 270 days (Jagtap, 1995). The growing period is usually bimodal, distributed with a statistically distinguishable period of lower precipitation around August, usually termed the 'August break'. The first wet season receives about 60% of the annual rainfall until mid August, while 40% falls in the second wet season. The dry season runs from November to March. Temperatures are usually lowest in August, with an average mean daily temperature of 20.1^{0}C, and highest in late March to early April, with an average mean daily temperature of 31.2^{0}C (Fig. 3.2). Climatological data collected during the period of this study, 2001 to 2002, are listed in the appendix 3.

3.1.2.3 Field establishment of the secondary experiment

Herbaceous legumes and natural vegetation were established on plots of 8m by 8m in 2001 at Ibadan in the derived savannah and Zaria in the northern Guinea savannah. The experimental design was a split plot fitted into a randomised complete block with four replications (Appendix 9). Main treatments and sub-plot treatments were the same as those of the main experiment established at Zaria in 2000 (cf. section 3.1.1.3). It is noteworthy that this experiment was established simultaneously at the two locations in 2001. Whilst the experimental plots were not subdivided before the cropping of maize in the second year, 2002, for logistical reasons, the two sub-plot treatments *M1* and *M2* were administered before the planting of maize (Table 3.3). Yields of forage and grain for this experiment were evaluated and reported separately in this thesis.

Table 3.3 Arrangement sub-plot of treatments showing the rotational plantings of herbaceous legumes and the test crop, *Zea mays* in the secondary experiments in Zaria in the northern Guinea savannah and Ibadan in the derived savannah.

Year	Subplot Treatment (*M1*)	Subplot Treatment (*M2*)
2001	HL	HL
2002	MZ	MZ

Management simulating farmer's systems are given as
M1= legume planted, left in the field
M2= legume planted, harvested and exported out of the field
HL = herbaceous legumes
MZ = maize, Zea mays Linn.

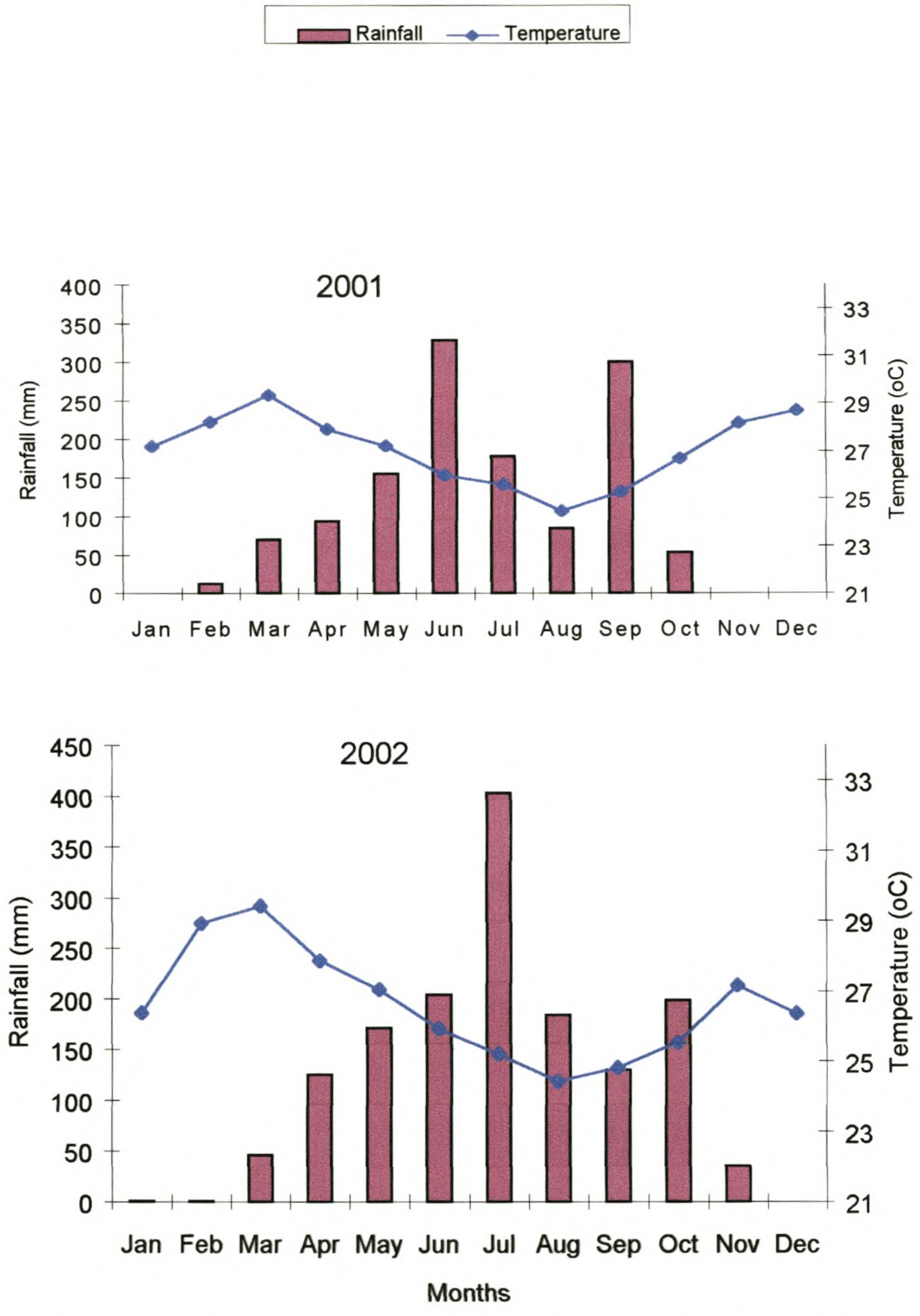

Figure 3.2 Monthly rainfall and mean daily temperature pattern in the derived savannah, Ibadan, during the experimental study.

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Chapter 4

Establishment, forage/grain yield and quality of selected herbaceous legumes

4.1 Introduction

Traditionally animals, and particularly ruminants, are an asset to society, by converting biomass from vast grazing areas into products useful for humans, e.g. manure, draft, milk, meat and security. However, a growing human population causes increased and shifting demands for food and other products. This results in the conversion of natural forests and grazing land into arable land for crop and *forage* production, thus leading to quantitative and qualitative changes in biomass availability for livestock feed (McIntire, Bourzat & Pingali, 1992; Winrock, 1992; Smith *et al.*, 1997). Livestock, and particularly ruminants, traditionally graze on natural vegetation, forest areas, roadside, fallow lands, crop re-growth or crop residues and crop by-products, which may be from the farm or purchased as supplements. When abundant feed is available, livestock can be considered a form of wealth, power and security; a perception based on the conversion of solar energy captured in biomass into products valuable for human society.

Given the current scenario of increasing human and livestock populations forcing agricultural intensification and placing immense demands on the natural resource base (de Haan, Steinfeld & Blackburn, 1997), herbaceous legumes are recognised to have the potential to alleviate some of the stresses faced by farmers (Winrock, 1992; Badiane & Delgado, 1995). Forage legumes, such as *Stylosanthes, Aeschynomene and Centrosema* species are recommended as livestock forage in tropical regions, especially where there is a pronounced dry season (Mohamed-Saleem & Suleiman, 1986; Muhr *et al.,* 1998; Tarawali, Peters & Schulze-Kraft, 1999b). More recently, it has become apparent that herbaceous legumes with multiple benefits are likely to be more acceptable to farmers in mixed crop-livestock systems, most notably those which provide some grain for human consumption, as well as improving soil fertility and/or providing livestock forage (Tarawali & Mohamed-Saleem, 1995; Tarawali & Peters, 1996; Weber, 1996). The present paper reports on the performance of selected species, with respect to establishment, forage and grain yield against the background of the potential interactions of suitable legumes in relation to weed dynamics, soil fertility and livestock management in crop-livestock systems.

4.2 Materials and Methods

4.2.1 Experimental layout, treatments and plant samplings

4.2.1.1 Main experiment

The main experiment was established as described in Section 3.1.1.3 in Chapter 3. The herbaceous legumes tested (Table 4.1) exhibit a broad spectrum of potential benefits, such as ground cover, dual purpose and forage, with different growth habits, growth cycles and dry season persistence (Muhr *et al.*, 1998). They are potentially suitable for various environments, often referred to as a

Table 4.1 Main treatments of the present study and criteria for selection of herbaceous legumes species, based on experiences from studies at similar sites.

Genus	Species	Abbr. used in Figures	Accession used	Estimated seeds m^{-2} sown[2]	Selection criteria
Aeschynomene	*histrix*	A. his	ILRI 12463	200	Promising forage legumes in recent evaluations, prolific seeder (Muhr *et al.*, 1998).
Glycine	*max*	*G. max*	TGX 1448 –2[E]	24	Introduced promiscuous dual-purpose cultivars developed by IITA. Enhanced capacity to kill seeds of parasitic weed *Striga hermonthica*, which attacks cereals (IITA 2002) and it is widely acceptable (Ogoke *et al.*, 2003).
Centrosema	*pascuorum*	C. pas	ILRI 9857	40	Effective soil coverage and soil ameliorant. Very palatable to livestock, even when dry. (Larbi *et al.*, 1999).
Vigna	*unguiculata*	V. ung	IT89KD-288	24	Potential for dual-purpose contributions (grain and forage), and soil ameliorant due to its low nitrogen harvest index (Carsky, Singh & Oyewole, 1999; Tarawali *et al.*, 2002))
Stylosanthes	*guianensis*	S. gui	ILRI 15557	200	Low soil fertility requirement, drought tolerance (Muhr, *et al.*, 1988).
Arachis	*hypogaea*	A. hyp	*UGA 5*	8	Forage and seed yields are joint products considered by crop-livestock farmers (Larbi *et al.*, 1999).
Natural vegetation		N. pas	NA	NA	Served as control to test the validity of information on selected legumes.

NA = Not applicable

[2] Larbi *et al.*, (1999)

"basket of systems" (Tarawali, 1994a&b; Merkel, 1996; Tarawali, Peters & Schulze-Kraft, 1999b). The selected legumes were monitored under three management systems simulating farmers' systems, as outlined in Table 4.2 (cf. chapter 3, section 3.1.1.3).

Table 4.2 Sub-plot treatments (management systems) in the main experiment carried out in northern Guinea savannah.

Designate	Description
M1	legume planted, left in the field
M2	legume planted, harvested and exported out of the field
M3	legume planted, harvested and fed to livestock, manure/urine/refused feeds returned

Herbaceous legumes were planted on the main plot of 25m by 50m in the NGS in a randomised complete block design with four replications (cf. Chapter 3, Section 3.1.1.3, Appendix 7). The planting was delayed by three weeks in the first year, 2000, however, planting in subsequent years was carried out at the onset of rains. Before sowing the legumes, the land was cleared and soil prepared to a fine tilth. Forage seeds were scarified using abrasion (sandpaper) until one or two seeds broke and damage to the seed coat was visible, after which seeds were sown at the recommended rates, assuming 95% viability (Tarawali 1994b; Merkel, 1996). All the herbaceous legumes received single super phosphate (SSP) at 20kg ha^{-1} P_2O_5 at planting, while minimum hand weeding was done to maintain pure legume stands during the establishment phase.

Planting of herbaceous legumes in 2001 and 2002 in this experiment in Zaria was done on rotational plots with different fallow lengths (cf. chapter 3, section 3.1.1.3 and Table 3.2).

Early growth, that is legume plant height and width was measured randomly across each main plot. Regeneration of legumes was also monitored in the subsequent years before field establishment. Legume and weed dry mass production was also determined after harvesting. Two quadrats measuring 1 m^2 on the two outer border rows on each side of the experimental plot were marked. All standing plants, including weeds, were cut at 10cm above soil surface and separated into weeds and planted legumes. The fresh weight of the harvested biomass was measured, then sub-samples of 200g to 300g fresh weights were obtained and oven dried at 60^0C to a constant weight for dry matter determination.

Biomass production of the legumes and natural vegetation at the end of the season were evaluated in the first year by net plot technique, i.e. only border plants were excluded per plot in the estimation of total biomass at harvest, while in subsequent years biomass assessments were carried out within a harvest area of 2m X 2m in five places across the plot. Noxious weeds, such as C*rotalaria spp.,* were removed from the natural vegetation occasionally and at harvest, in order not to contaminate feed residues. This was done for all subplots containing herbaceous legumes in the experiment. Pods from grain legumes were hand picked from the sample areas and weighed after biomass was determined. A sub-sample of pods with grain from each of the planted grain legumes was weighed and dried in an oven at 70°C for 48 hours for dry grain matter determination.

Another sub-sample was dried at temperatures set at 65°C for 48 hours for chemical analysis. Only main treatments, i.e. herbaceous legume species, were considered and no sub-sampling of subplots was done. These samples were taken each year for the duration of the experiment.

4.2.1.2 Secondary experiment

These experiments with a plot size of 8m by 8m were set up at the two locations, northern Guinea savannah and derived savannah respectively in 2001, as described in Chapter 3, Section 3.1.2.3. As indicated, only two of the sub-plot treatments, *M1,* legume residues left in the field, *M2*, and legume residues exported from the field, were used in this experiment for logistical reasons. Because the herbaceous legumes were established for the first time in 2001 in this experiment, and maize was planted in 2002, biomass production figures are available for 2001 only.

Biomass production of the legumes and natural vegetation at the end of the season was evaluated as in the second and third years of the main experiment, except for the fact that only three 2m X 2m plots were used due to size constraints.

4.2.2 Chemical analyses of plant residue

Plant samples were bulked over replications prior to chemical analyses. Dried samples were milled in a laboratory hammer mill (Retch Muhle, Dietz) to pass through a 1.0mm sieve. These samples were stored in airtight containers, labelled and kept in a dark cupboard at room temperature until required for nitrogen and phosphorus content determination. For total nitrogen, samples were digested with a mixture of concentrated H_2SO_4 and H_2O_2 (30.0%) in the presence of one Kjeldahl catalyst tablet (1 g Na_2SO_4 + 0.05 g Selenium) in a Tecator Digestor System using the Technicon AAII, as described by Tel and Rao (1982). Nitrogen contents were subsequently converted to crude protein by multiplying by 6.23. Organic matter, phosphorus, crude protein (CP), acid detergent fibre (ADF) and lignin were determined according to procedures described by the AOAC (1984), while neutral detergent fibre (NDF) was determined in accordance to Van Soest, Robertson and Lewis, (1991). Dry matter digestibility (DMD) was calculated using the Van Soest (1967) summation equation and reported by Kallah *et al.,* (2000) as follows:

$$DMD = 0.98\ CC + NDF\ (1.473 - 0.789 \log ADF) - 12.9,$$

where CC is cell contents, NDF the neutral detergent fibre and ADF the acid detergent fibre.

4.2.3 Statistics

Data were arranged sequentially, showing the main plot treatments, sub-plot treatments and replications prior to statistical analysis. Data were analyzed using Mixed Models Procedure of Statistical Analysis System (SAS) (Little *et al*., 1996). The Standard error of difference (Sed) values are used in a similar way to the Lsd command of the Proc. GLM (Generalized least square means) procedure of SAS, to determine if significant differences between treatment means occur.

4.3 Results

4.3.1 Main experiment

In general, the grain legumes *V. unguiculata* and *G. max* showed the most vigorous growth in terms of both plant height and width in 2000 (Fig. 4.1). Although significantly less than *V. unguiculata* and *G. max, C. pascuorum* showed the most rapid growth with regard to both plant height and width among the forage legumes.

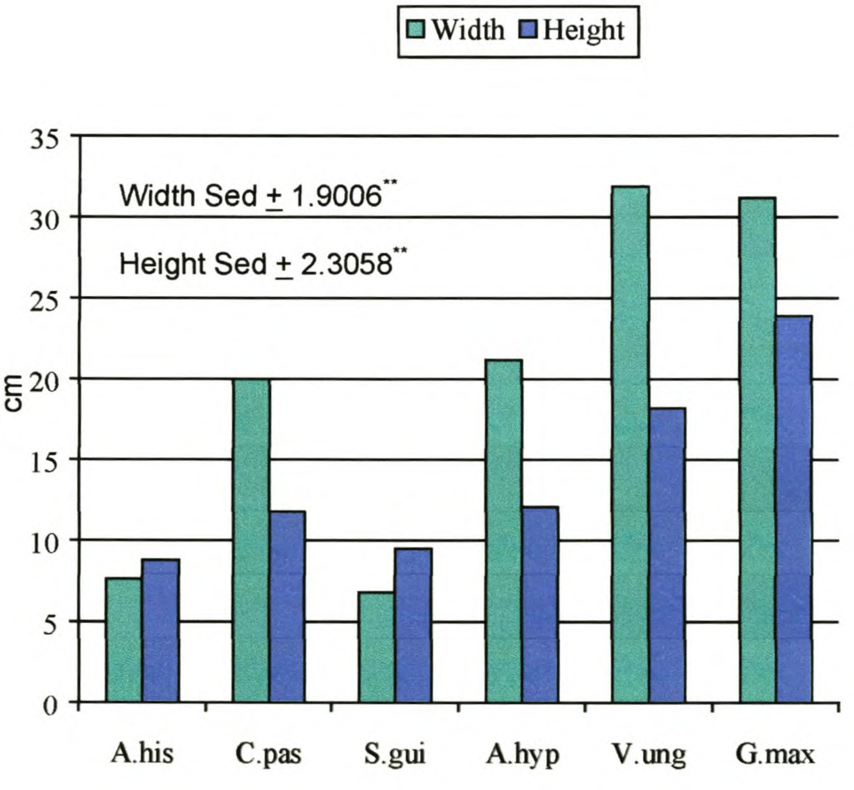

Figure 4.1 Mean width and height of individual herbaceous legume plants, measured one month after planting in the main experiment in the northern Guinea savannah in 2000.

Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata.

4.3.1.1 Self-regeneration of forage legumes and weeds in 2001

Assessment of associated vegetation, i.e. weeds plus regenerating *A. histrix, S. guianensis* and *C. pascuorum* after the dry season in June 2001, but before planting, revealed a high number of forage legume seedlings, but no grain legume seedlings. Data presented in Table 4.3 indicate that *S. guianensis* regenerated profusely and had a significantly higher (P<0.05) biomass, compared to the other two forage legumes. Weed biomass results prior to field re-establishment in the northern Guinea savannah in 2001 showed significant differences (P<0.05) between treatments. *G. max* caused a significantly lower weed biomass compared to *V. unguiculata,* while *S. guianensis* showed a significantly (P<0.05) lower weed biomass than *C. pascuorum*. Apart from *V. unguiculata* and *C. pascuorum,* all legumes tested did suppress weeds significantly more than natural vegetation (Table 4.3).

Table 4.3 Regeneration of weeds and forage legumes at field establishment in the main experiment in the northern Guinea savannah in 2001.

Treatments	Legume biomass (regeneration)	Weed biomass
	Mg ha^{-1}	
A. histrix	0.61	4.31
C. pascuorum	1.06	5.17
S. guianensis	2.02	3.32
A. hypogaea	-	4.44
V. unguiculata	-	5.75
G. max	-	3.93
Natural vegetation	-	5.81
Sed±	0.435**	0.972**

***significant at P=0.05*

4.3.1.2 Forage and grain yields

Mean forage dry matter and grain yield of herbaceous legumes compared to dry matter yield from natural vegetation measured on the main experiment in the northern Guinea savannah for the years 2000 – 2002 are presented in Table 4.4. In the first year, dry matter yield for *S. guianensis* was significantly ($P < 0.05$) higher than for *A. histrix*, but not *C. pascuorum,* amongst the forage legumes. Similarly, dry matter yield for *A. hypogaea* and *G. max* was significantly higher than for *V. unguiculata* (Table 4.4).

There was a general increase in the amount of dry matter produced by forage legumes in 2001. Dry matter yield for *S. guianensis* was significantly higher compared to the other two forage legumes (Table 4.4). On the other hand, dry matter yield for the grain legumes in 2001 stayed almost the same for *A. hypogaea*, which was significantly higher than for the other two grain legumes, which declined for *G. max* and doubled for *V. unguiculata*. In 2002, after one year of maize, the legume dry matter production dropped to levels of about 50% of those in 2001, except for *G. max* and *V. unguiculata*, which increased their dry matter production. In contrast to other years, *C. pascuorum* produced significantly more dry matter than the other two forage legumes in this year, while *G. max* out-yielded the other grain legumes.

For logistical reasons, no data on grain yield was in collected in 2000. Results from 2001 showed that there were statistically significant ($P<0.05$) differences between grain yield of all three grain legumes. *A. hypogaea* produced the most grain, followed by *G. max* and *V. unguiculata*. Results on grain yield in 2002 show that *A. hypogaea* grain yield declined to 0.239Mg ha^{-1}, whereas the grain yield of *G. max* and *V. unguiculata* increased, with the result that both *G. max* and *V. unguiculata* produced significantly higher yields compared to *A. hypogaea* in this year (Table 4.4).

Results indicate no significant ($P>0.05$) interactions between management systems and herbaceous legumes (Fig. 4.2b). Management systems imposed (cf. Tables 4.2) indicate no significant differences at $P=0.05$ (Fig. 4.2c), although differences between dry matter yield for *M2* and the other management systems appears to be marginally bigger than the Sed value (Fig. 4.2c). However, this can happen sometimes when working with the SAS program. Considering the performance of legume species, there were significant differences ($P < 0.05$) (Fig. 4.2 a).

In 2002 there was a decrease in total dry matter yield compared to 2001. Significant interactions ($P<0.05$) occurred between legume species and management system (Fig. 4.3b). *A. histrix* and *C. pascuorum* appeared to produce more dry matter under *M2* compared to *M1*, but not more than *M3*. *S. guianensis*, *V. unguiculata* and *G. max* produced more dry matter under *M3* compared to *M1* and *M2*. *A. hypogaea* produced about the same amount of dry matter under *M2* and *M3,* which was significantly more than under natural vegetation. There was no clear trend visible, although there seemed to be a tendency for the legumes to produce more dry matter under *M3*.

4.3.2 Secondary experiment

With respect to the secondary experiment in the northern Guinea savannah and the derived savannah, in 2001 much more dry matter was produced in the derived savannah than in the northern Guinea savannah (Fig. 4.4). Among the forage legumes, *C. pascuorum* and *S. guianensis* produced significantly ($P<0.05$) more dry matter at both localities than *A. histrix*. *V. unguiculata* produced a significantly higher amount of dry matter than the other two-grain legumes in the derived savannah, but not in the northern Guinea savannah (Fig. 4.4). It is noteworthy that dry matter yield for natural vegetation was consistently higher than for herbaceous legumes at both locations (Fig. 4.4).

Table 4.4 Mean forage dry matter and grain yield of selected herbaceous legumes from different treatment combinations in the Northern Guinea Savannah.

Herbaceous legumes	Yr. 2000[3]		Yr. 2001[4]		Yr. 2002[5]	
	Grain	Forage DM	Grain	Forage DM	Grain	Forage DM
	$Mg\ ha^{-1}$					
A. histrix	-	0.550	-	5.461	-	2.968
C. pascuorum	-	1.744	-	5.578	-	3.670
S. guianensis	-	2.050	-	9.406	-	2.344
A. hypogaea	-	3.342	1.254	3.854	0.239	2.866
G. max	-	3.234	0.809	0.432	1.488	3.604
V. unguiculata	-	0.673	0.509	1.376	0.888	1.557
Natural vegetation	-	-	-	6.014	-	1.975
Sed ±	-	0.483**	0.231**	1.044**	0.080**	0.353**

*** Significant at P=0.05; DM = Dry matter*

[3] dry matter yield at the establishment phase in 2000.
[4] dry matter yield after two-year fallow with legumes in 2001.
[5] dry matter yield following rotational fallow-maize-fallow in 2002.

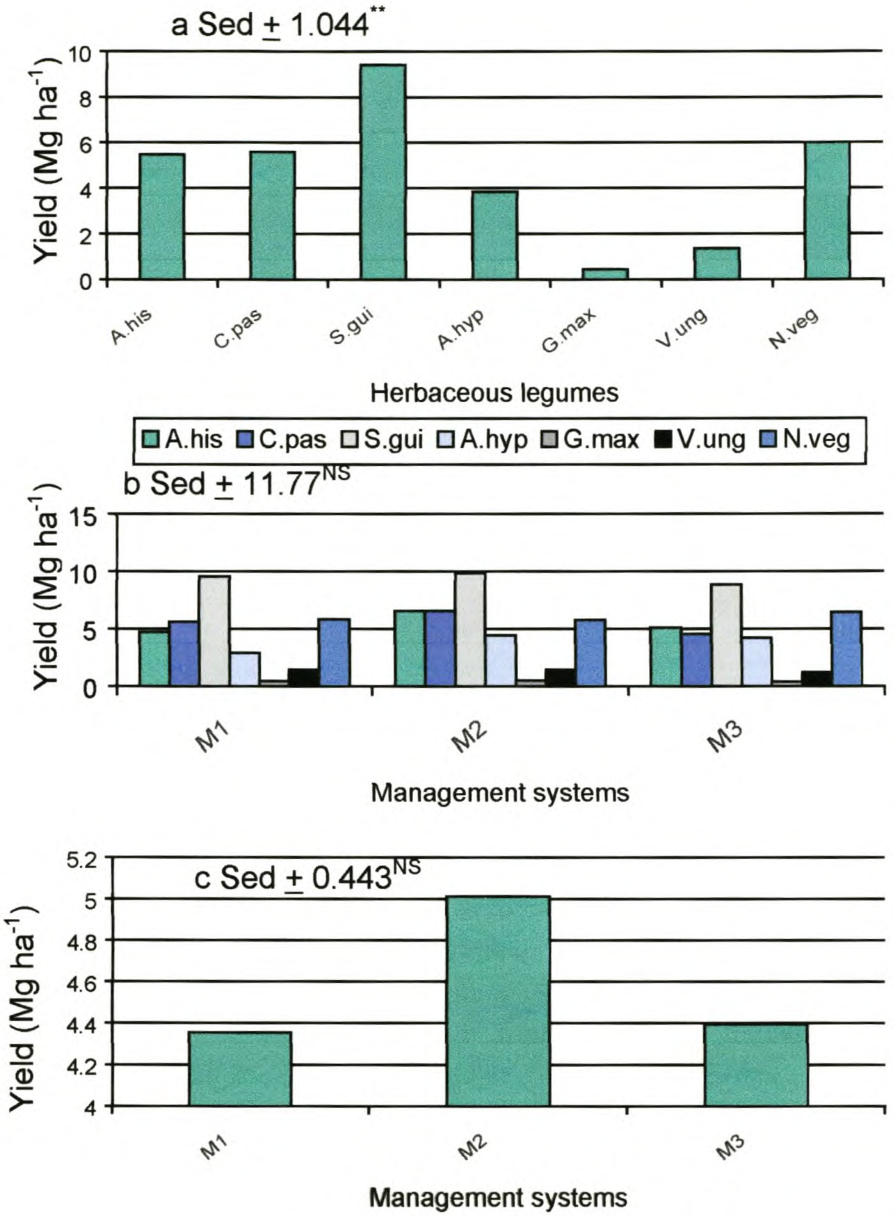

Figure 4.2 Forage dry matter yield of selected herbaceous legumes after two years of fallow with legumes in 2001 in the northern Guinea savannah.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

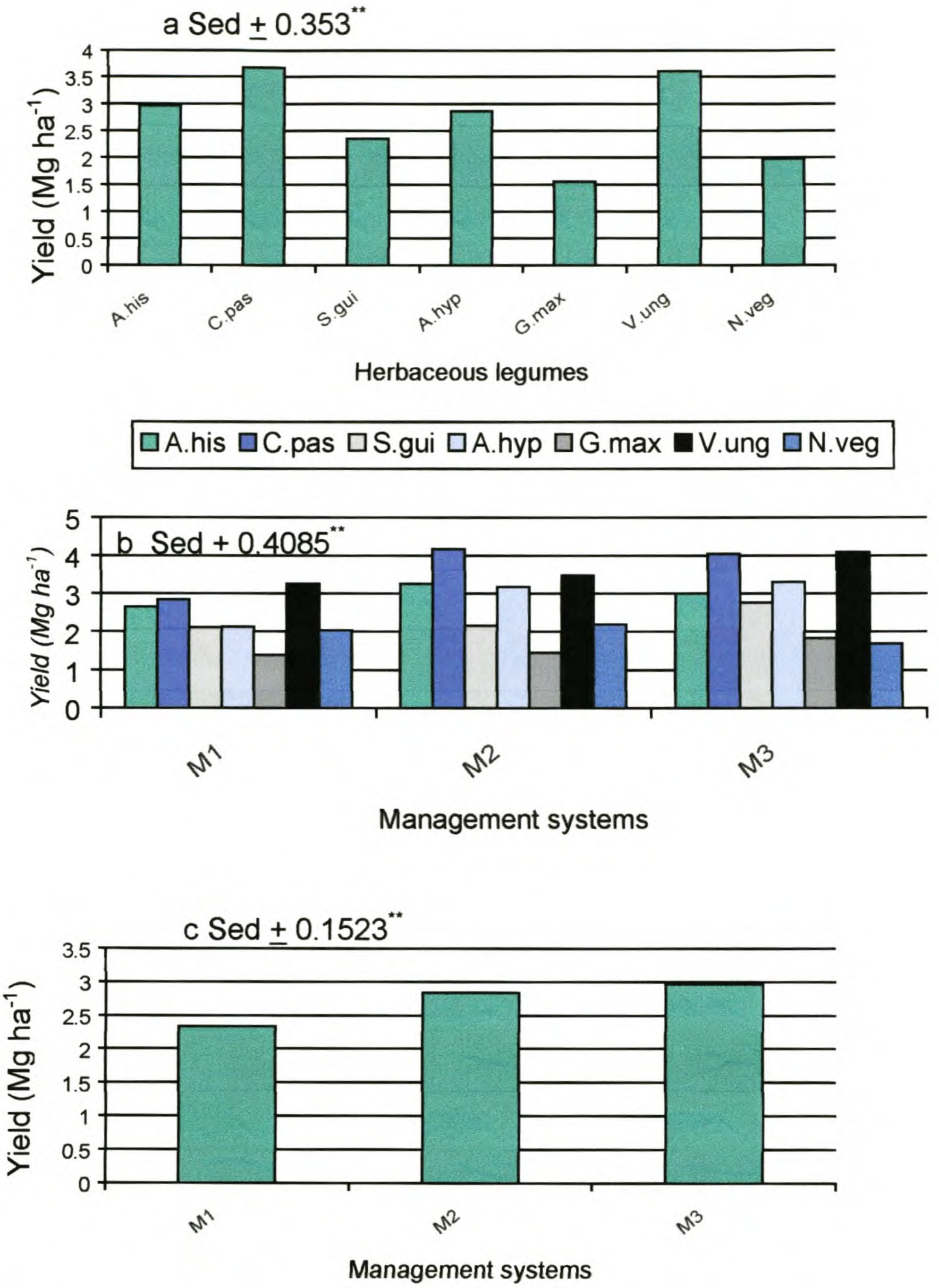

Figure 4.3 Forage dry matter yield of selected herbaceous legumes in 2002, following a legume-maize-legume rotation in the northern Guinea savannah.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

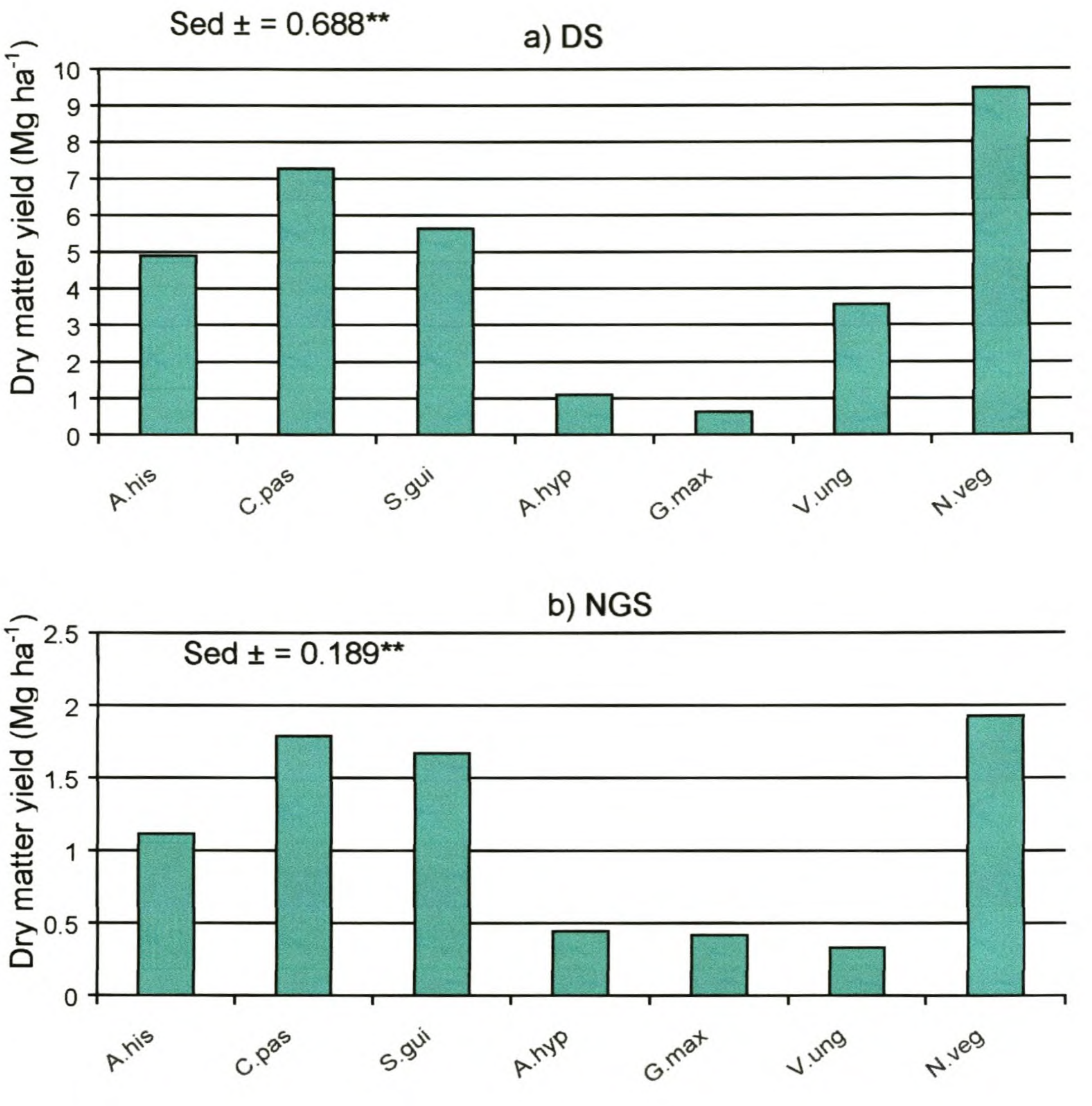

Figure 4.4 The effect of location on dry matter yield of selected herbaceous legumes in the secondary experiment in the northern Guinea savannah and the derived savannah in 2001.

a) DS= derived savannah, b) NGS = northern Guinea savannah.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation.

4.3.3 Forage quality

Mean values for organic matter, crude protein, NDF, ADF and lignin for the selected herbaceous legumes over three years are presented in Table 4.5. Mean organic matter content varied from 76.4% for *A. hypogaea* to 95.4% for *G. max.* Crude protein was fairly high in all the selected herbaceous legumes, with a range of 11.2% for *G. max* to 17.3% for *A. hypogaea,* while the values were lower (8.6%) for the natural vegetation.

Generally, NDF, ADF, and lignin levels were lowest for *A. hypogaea* and highest for *G. max.* Within the forage legumes, these constituents were the highest for *A. histrix* followed by *S. guianensis* and the lowest for *C. pascuorum.* In the grain legumes, however, higher values were found for *G. max* and *S. guianensis* and lower values for *A. hypogaea.* The dry matter digestibility had the same trend as that of cell wall constituents, ranging from 17.8% for *A. hypogaea*, to 38.0% for *G. max*.

The concentrations of nitrogen and phosphorus in the six selected herbaceous legumes and natural vegetation are given in Table 4.6. Among the herbaceous legumes, the highest mean value of 24.3g Nkg^{-1} DM was found for *A. hypogaea* and the lowest mean value of 17.6g Nkg^{-1} DM for *G. max*. Values for all herbaceous legumes tested were higher than the 15.4g Nkg^{-1} DM for natural vegetation. A narrow range, 1.585 – 1.919g Pkg^{-1} DM, was observed for phosphorus across the selected herbaceous legumes and natural vegetation.

Table 4.5 Chemical analyses of selected herbaceous legumes and natural vegetation (means of 2000, 2001 and 2002) from experimental plots in the northern Guinea savannah.

	Components	Mean	Std. Dev.	Range
		←	% DM	→
A. histrix	OM	90.9	8.4	78.4 - 96.1
C. pascuorum	OM	90.6	4.2	84.3 - 93.4
S. guianensis	OM	93.8	1.4	92.2 - 95.3
A. hypogaea	OM	76.4	8.1	65.6 - 85.3
V. unguiculata	OM	92.2	2.6	88.8 - 95.0
G. max	OM	95.4	1.6	94.1 - 97.5
Natural vegetation	OM	88.5	5.8	79.9 - 92.7
A. histrix	CP	13.3	8.9	5.7 - 28.2
C. pascuorum	CP	12.1	5.3	5.5 - 19.0
S. guianensis	CP	11.7	3.6	6.1 – 17.0
A. hypogaea	CP	17.3	3.2	11.5 - 21.6
V. unguiculata	CP	13.0	4.5	8.6 - 21.9
G. max	CP	11.2	4.7	5.9 - 19.3
Natural vegetation	CP	8.6	2.7	4.7 - 11.4
A. histrix	NDF	70.8	6.9	62.5 - 79.4
C. pascuorum	NDF	66.8	8.8	59.4 - 77.6
S. guianensis	NDF	69.3	4.2	65.5 - 73.0
A. hypogaea	NDF	35.5	5.6	29.1 - 42.7
V. unguiculata	NDF	63.3	6.2	54.6 - 68.4
G. max	NDF	72.9	5.7	67.3 - 80.6
Natural vegetation	NDF	69.8	6.1	61.7 - 74.5
A. histrix	ADF	54.0	8.0	43.8 - 66.4
C. pascuorum	ADF	49.0	7.1	34.3 – 56.0
S. guianensis	ADF	53.9	7.1	43.1 - 64.2
A. hypogaea	ADF	37.7	12.4	22.3 - 56.9
V. unguiculata	ADF	52.4	5.3	45.9 - 60.9
G. max	ADF	56.3	10.0	44.1 - 73.4
Natural vegetation	ADF	50.7	3.5	43.7 - 54.3
A. histrix	LIGNIN	13.2	2.0	11.3 - 16.4
C. pascuorum	LIGNIN	12.3	2.3	8.1 - 15.2
S. guianensis	LIGNIN	13.2	0.7	11.8 - 14.1
A. hypogaea	LIGNIN	11.3	5.1	6.7 - 22.3
V. unguiculata	LIGNIN	12.3	1.0	10.9 - 13.0
G. max	LIGNIN	14.0	2.1	11.1 - 17.5
Natural vegetation	LIGNIN	12.4	3.7	8.7 - 20.1
A. histrix	DMD	37.2	3.4	33.7 - 41.5
C. pascuorum	DMD	33.0	5.2	26.6 - 38.4
S. guianensis	DMD	37.0	2.6	34.5 - 39.7
A. hypogaea	DMD	17.8	2.9	14.4 - 21.2
V. unguiculata	DMD	34.8	4.1	29.5 - 38.6
G. max	DMD	38.0	3.3	34.1 - 41.9
Natural vegetation	DMD	36.0	2.9	33.2 - 39.6

OM= organic matter; CP= crude protein; NDF= Neutral detergent fibre; ADF= Acid detergent fibre; DMD= Dry matter digestibility

Table 4.6 Mean phosphorus and nitrogen levels in selected herbaceous legumes and natural vegetation in 2000, 2001 and 2002 in the experimental plots in the northern Guinea savannah.

	Element	Mean	Std Dev. $g\ kg^{-1}$ DM	Range
A. histrix	Phosphorus	1.9	0.9	0.8 - 3.5
C. pascuorum	Phosphorus	1.6	0.8	0.9 - 3.5
S. guianensis	Phosphorus	1.9	0.7	0.6 - 2.9
A. hypogaea	Phosphorus	1.8	0.6	0.8 - 2.6
G. max	Phosphorus	1.6	0.8	0.6 - 3.1
V. unguiculata	Phosphorus	1.7	0.7	0.9 - 3.0
Natural vegetation	Phosphorus	1.9	0.7	1.0 - 2.8
A. histrix	Nitrogen	20.2	11.6	9.2 - 45.3
C. pascuorum	Nitrogen	19.6	7.0	8.8 - 30.5
S. guianensis	Nitrogen	18.8	4.7	9.8 - 25.6
A. hypogaea	Nitrogen	24.3	7.5	11.7 - 34.7
G. max	Nitrogen	17.6	6.4	9.5 - 30.9
V. unguiculata	Nitrogen	19.3	6.7	11.1 - 35.2
Natural vegetation	Nitrogen	15.4	4.5	7.6 - 21.9

4.4 Discussion

4.4.1 Ease of establishment

Ecological adaptation is an important factor for legume integration into farming systems (Anon, 1999). The present study has demonstrated that herbaceous legumes tested are well adapted to the prevailing conditions in the study localities. However, one striking feature of the data was the poor observed establishment data during the first cropping year. This problem was minimised by careful handling of input, such as seed scarification for forages and planting after sufficient rain has fallen. Results showed that *V. unguiculata* and *G. max* initially grew more vigorously than all other legumes tested, while *A. histrix* grew very slowly. Species with slow initial growth are, however, not likely to be accepted by farmers who face acute labour shortages at the beginning of the rainy season, when planting and weeding absorb most of their labour force (David, 1995). Fast-growing and easily established legumes could be a labour-saving alternative. Although the present study did not cover studies on pest incidence, we know that this is an important factor when selecting legumes for integration into food crops that are susceptible to nematode infection (Tarawali, 1994a). The poor growth of *A. histrix* may be due to nematode infection while that of *S. guianensis* may be due to this species susceptibility to anthracnose but plant did not show any visual symptoms of the disease.

4.4.2 Regeneration potential of forage legumes.

An advantage of leguminous species over natural fallow vegetation during the dry season is an improvement of herbage quality, more so than quantity. This is caused by self-regeneration of the legumes after a cropping phase (Jones *et al.*, 1991). In contrast to grain legumes, where no regeneration occurred after the dry season, forage legumes, and especially *S. guianensis,* regenerated profusely. These tendencies were due to the ability of forage legumes, *A. histrix, S. guianensis and C. pascuorum*, to produce enough mature seed before the onset of the dry season. These observations were consistent with the findings of Peters, Tarawali & Alkamper (1994) and Tarawali *et al.* (1995).

4.4.3. Dry matter yield and quality of forage residues

The grain yield from grain legumes has the potential to contribute food for human consumption, in addition to forage for livestock. However, the addition of the aforementioned attributes gives grain legumes an advantage over forage legumes. For instance, Larbi *et al.* (1999) reported on *A. hypogaea* seeds as a major source of oil for humans, and the cake after oil extraction as a major source of protein supplement for livestock. The forage (haulms), after pod harvesting were fed to ruminants in the dry season. In this study, the contribution of *A. hypogaea* in terms of grain production varied considerably between 2001 and 2002. The poor grain and forage production in 2002 after maize in the previous year, may indicate that *A. hypogaea* do not fix nitrogen as effectively as the other two grain legumes, because it is more dependent on the carry-over nitrogen balance from the previous season. Over all management systems however, *A. hypogaea* appeared to produce the highest amount of forage amongst the grain legumes.

In the context of the two locations for this study, dry matter crop residues realised from *S. guianensis, C. pascuorum, A. histrix, A. hypogaea, S. guianensis* and *G. max* in the derived savannah were significantly higher than the northern Guinea savannah, primarily due to the different climatic conditions, which is in agreement with the findings by Tarawali, Peters and Schulze-Kraft (1999a). Generally, the high amount of leaf litter realised from these legumes across the two localities showed that they have potential as forage crops, provided humidity does not alter its forage quality as opined by McCown and Wall (1989).

The average crude protein ranges from 11.2% to 17.3% for the legumes and was significantly ($p<0.05$) higher than the 8.6% found in natural vegetation. These figures are comparable to those found in introduced legumes in the coastal grassland of West Africa (Minson, 1990; Ikhimioya & Olagunju 1996; Kallah *et al.*, 2000). Earlier studies on a wide range of herbaceous legumes indicate crude protein to be in the range of 9.5 –35.9% (Tarawali & Mohamed-Saleem, 1995). The six species in the present study were within this range, indicating that they are fairly good in terms of their higher quality. Moreover, judging from the calculated coefficients of dry matter digestibility (DMD), all the legumes, except *A. hypogaea*, have digestibility above 30%, which is considered adequate for sustaining animal performance (Kallah *et al.*, 2000). If these legumes were combined with grass in ration formulation, nutrient deficits in the natural vegetation could be overcome.

The ranges of NDF, ADF and lignin were comparable to earlier reports for several forage species in the tropics (Nsahlai *et al.*, 1994). Mineral composition of phosphorus varies with soil fertility, plant species and stage of maturity. Advantages of this to cropping systems, were the ability of the legumes to grow rapidly to cover the soil during the raining season and to persist as live or dead mulch during the dry season, in addition to their valued properties as forage.

4.5 Conclusion

Herbaceous legumes are important components of integrated crop-livestock systems, especially in the moist savannah of Nigeria. The three forage legumes, *A. histrix, C. pascuorum and S. guianensis*, and three grain legumes, *A. hypogaea*, *G. max* and *V. unguiculata*, evaluated are potentially useful legumes for integration into sown pasture production. These species are quite promising for improving available forage in the northern Guinea savannah in terms of protein (up to 17%), and energy (up to 38%). Studies of their agronomic potentials revealed that they have a significantly higher dry matter production in the derived savannah than the northern Guinea savannah, though these legumes are in higher demand in the northern Guinea savannah for dry season feeding. Intensive studies to evaluate valuable attributes of these legumes in relation to weed dynamics, soil fertility and livestock management in crop-livestock systems are presented in subsequent chapters in this thesis.

In a simplified ranking of herbaceous legumes in this study, several parameters were considered (Table 4.7). The parameters considered are regeneration of legumes after dry season, grain dry matter yield, forage dry matter yield, weed suppression ability, mineral nitrogen and phosphorus contents, organic matter and dry matter digestibility, which were considered vital in smallholder crop-livestock farming systems.

Among the forage legumes, *S. guianensis* was ranked first, followed by *A. histrix* and *C. pascuorum*. A similar ranking for the grain legumes indicates that *G. max* scored best, with *A. hypogaea* and *V. unguiculata* following, in that order. It is pertinent to note that this is an overall scoring system; different legumes performed differently over years and within management systems as outlined in the subsequent chapters. However, this preliminary result could be informative for smallholder farmers in the northern Guinea savannah, thereby contributing to the sustainability of such intensive systems.

Table 4.7. Overall performance of selected herbaceous legumes, as ranked in terms of the above-mentioned parameters.

Herbaceous legumes	Reg.	Grain yield	Forage yield	Weed supp.	N content	P content	Organic Matter	DMD	Total	Ranking based on legume type
A. histrix	1	NA	1	2	3	3	2	3	15	**2nd**
C. pascuorum	2	NA	2	3	2	2	1	1	13	**3rd**
S. guianensis	3	NA	3	2	1	3	3	2	17	**1st**
A. hypogaea	NA	2	2	2	3	1	1	1	12	**2nd**
V. unguiculata	NA	1	1	1	1	2	2	2	10	**3rd**
G. max	NA	3	3	3	2	3	3	3	20	**1st**

NA= Not applicable
Reg.= regeneration potential
Weed supp. = weed suppression potential
DMD= Dry matter digestibility

Ranking:
1 = lowest performed indicator
2= medium performed indicator
3 = highest performed indicator

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Chapter 5

Rotational effects of legumes and management systems on soil fertility and cereal yields

5.1 Introduction

In many areas of the West African savannah, the intensification of agricultural systems has resulted in declining nutrient availability, soil acidification, soil compaction and a build-up of pest problems, all of which seriously affect soil productivity (Weber, 1996). However, technological systems have been developed for long-term maintenance of crop productivity (Kang, Wilson & Sipkens, 1981; Okigbo, 1991), and recently, there has been a renewed effort to address these problems through the introduction of legumes into the production system (COMBS, 1993; Winrock, 1992; Tarawali, 1994; Badiane & Delgado, 1995; Delgado et al., 1999; Tarawali et al., 2001).

Nitrogen is often the most important nutrient element required for cereal production and yet it is the most limited nutrient in the moist savannah as land use intensifies (Sanchez, 1976; Oikeh *et al*., 1998). The use of commercial fertilisers to address this constraint in tropical land use systems is restricted for several reasons (Bationo & Mokwunye, 1991). Various attempts to maintain and improve the soil fertility through application of organic manure, fertiliser and mulching have been documented as promising ways of improving crop growth and yield (Tarawali, 1994). Depending on the size of the farm, to produce manure in large quantities for bigger farms is often a problem and the cost of transportation of such manure to farmlands is prohibitive. Plant residue management for the supply of nitrogen and other nutrients has become a viable alternative to improve tropical cropping in rotations (Tarawali, 1994).

Therefore, the main objective was to assess the extent of variation in residual effects contributed by legumes through cereal performance and grain seed yields. A second objective was to find out if correlations existed between desirable agronomic characteristics from different cropping treatments based on length of fallow with legumes. The long-term goal is to select herbaceous legumes with economic potential for forage and seed production for integration in smallholder crop-livestock systems, based on agronomic characteristics. This chapter explores the potential of these objectives to investigate agronomic characteristics of soil productivity under varying lengths of fallow, using maize, *Zea mays* as a test crop.

5.2 Materials and Methods

5.2.1 Soil sampling and analysis

At the beginning of the experiment, soil was sampled at 0cm to10cm depth and bulked across each replication. Subsequent soil samplings were carried out before the planting of maize in 2001 and 2002 from each sub-plot at 0cm to 10cm, using a soil auger precision core sampler. Ten cores were collected from each sub plot, bulked and sub-sampled for chemical analysis. The sub-samples were air-dried and crushed to pass through 0.5mm and 2mm sieves. Chemical analysis was performed for pH, i.e. soil pH in H_20 (1:1 soil water ratio) (Glass-electrode method), total nitrogen (Kjeldahl digestion method), phosphorous (Bray -1- method), exchangeable cations K, Mg and Ca and Na (extraction method in 1N ammonium acetate (NH_4OAC) of pH 7 and EDTA solution), total acidity (titration method) and organic carbon (Walkley-black digestion method). Detailed procedures for each of these analyses are given in appendix 12.

5.2.2 Crop establishment

The main experiment was carried out in the northern Guinea savannah, while the secondary experiments were simultaneously conducted at derived savannah and northern Guinea savannah respectively. The experimental design for the three experiments reported in this thesis, is a split-split plot fitted into a randomised complete block design (RCBD), with four replications. Main plot and sub-plot treatments are described in chapter 3, sections 3.1.1.3 and 3.1.2.3.

5.2.2.1 The main experiment in the northern Guinea savannah

The main experiment in the northern Guinea savannah commenced in 2000 with the establishment of herbaceous legumes (cf. chapter 3 section 3.1.1.3; Fig 3.2). The cropping of maize actually commenced in 2001 after the generation of compost through feeding legume residues to small ruminants. The compost generated was applied in 2001 and 2002 before the planting of maize. In 2001, the main plot was divided into two equal parts to accommodate a split into continuous legume cropping, tagged *2yrL* and maize following the legume crop, tagged *1yrL1yrM* (Plate 5.1; cf. Figure 3.2, Chapter 3). In 2002, the plots that received a one-year legume fallow in 2000, followed by one-year of maize in 2001 was sub-divided to allow continuous maize cropping, tagged *1yrL2yrM*, and another legume fallow. The plots that received two years of legume fallow, i.e. in 2000 and 2001, were planted to maize and tagged *2yrL1yrM* (cf appendix 8). The grain and stover yields of the maize crop are evaluated regarding the different rotation systems described above. Different rotation systems are indicated by *1yrL1yrM, 1yrL2yrM* and *2yrL1yrM* (Plate 5.2).

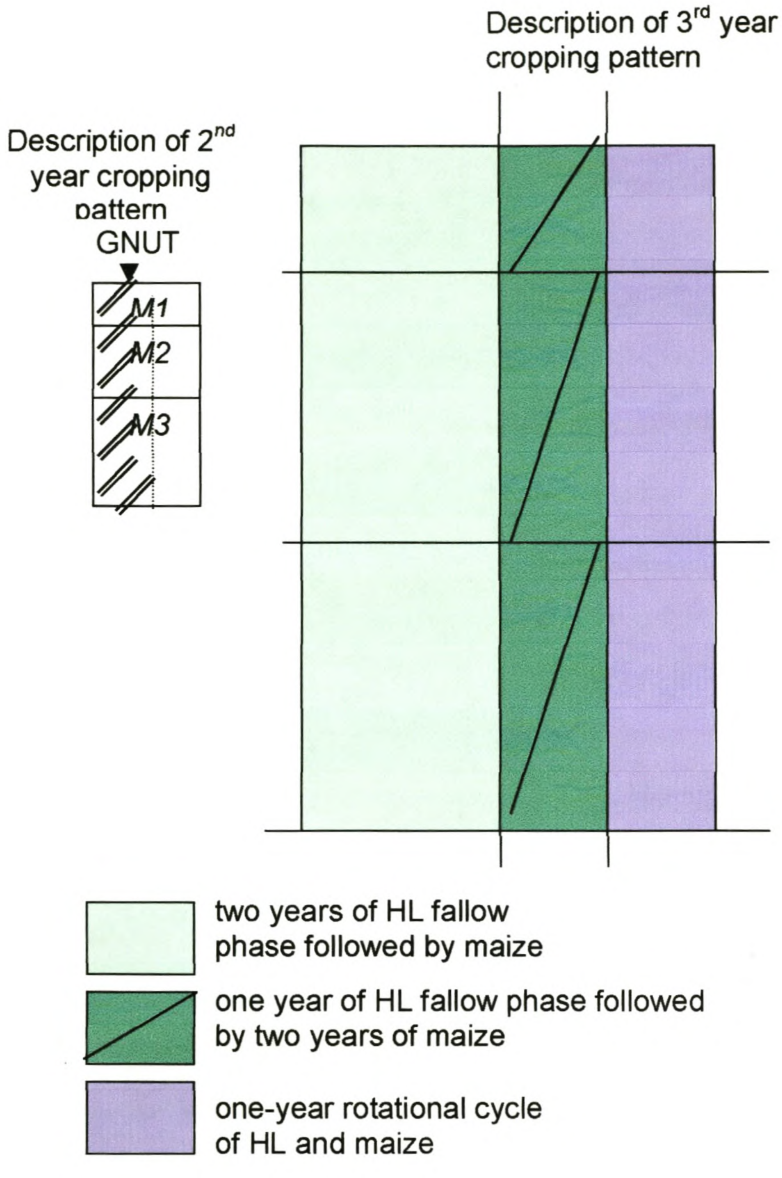


Plate 5.1 Pictorial view of rotational planting of maize in the main experiment in the northern Guinea savannah in 2001 and 2002.

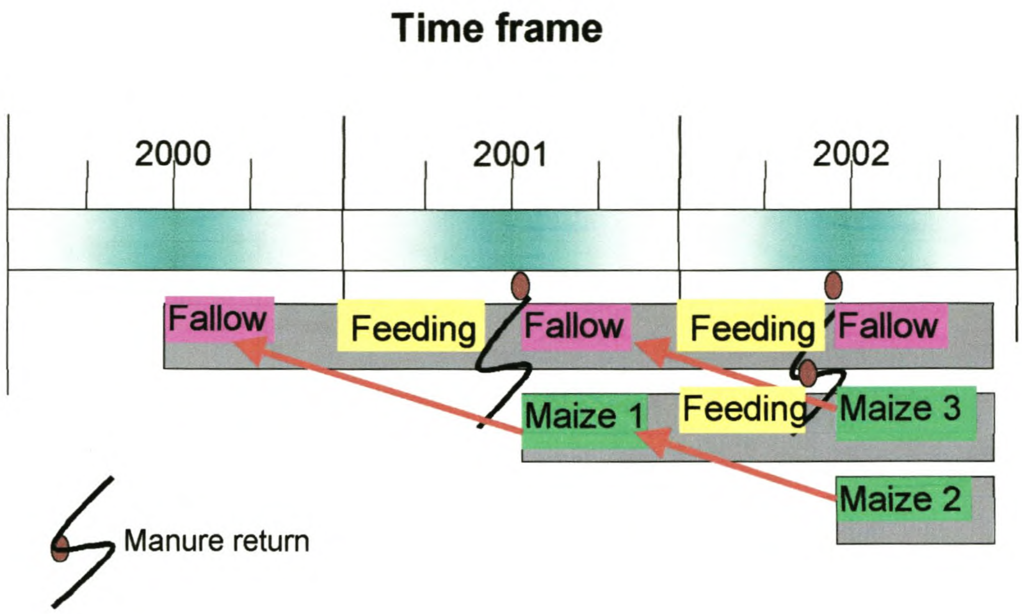


Plate 5.2: The main cropping patterns of legume fallow and maize in the main experiment in the northern Guinea savannah.

Fallow = relates to the period herbaceous legumes were planted before maize cropping.
Feeding= relates feeding of small ruminants in the dry season.
Manure return = specifies the period when compost was applied to the field.
Maize 1 = Maize planted after one-year fallow with legumes tagged 1yrL1yrM.
Maize 2 = Maize planted following a continuous cropping of maize tagged 1yrL2yrM.
Maize 3 = Maize planted after two-year fallow with legumes tagged 2yrL1yrM.

5.2.2.2. Secondary experiment in the derived savannah and the northern Guinea savannah

The secondary experiment commenced simultaneously in the derived savannah and northern Guinea savannah in 2001. Field establishment and treatments are discussed (cf. chapter 3, section 3.1.2.3). As indicated, main treatments were similar to those of the main experiment, but on a smaller plot size of 8m by 8m (Appendix 9). Only two of the sub-plot treatments featured in this experiment. These are *M1,* legume residues left in the field, and *M2*, legume residues exported from the field. For logistical reasons, the third sub-plot treatment was impractical to carry out. The feeding trial was not feasible within the time limit of the experiment.

5.2.2.3 Crop management and evaluation

The procedure used in estimating crop performance was similar for the main experiment and secondary experiments, with the exception of the maize cultivar planted in the derived savannah. An improved *Striga* resistant maize variety ACR 92 TZECOMPS.5-W (EARLY) was used as the test crop throughout the period of the experiment in the northern Guinea savannah, while an improved maize variety, EV.IWOSTR C1, was used as test crop in the derived savannah. Maize was planted at a spacing of 0.75m by 1m, with two seeds per hole, without fertiliser application. Weeding was performed twice, three and six weeks after planting. Maize performance was evaluated within a sampled area of 10m by 3.75m in the main experiment, while a sampled area of 6m by 3.75m was used for the secondary experiment in both localities.

Maize plant height was measured at monthly intervals. Total grain yield and stover weight were evaluated at harvest by sampling five rows for each plot. The fresh weight of harvested biomass was measured on the field, while sub-samples of about 200g to 300g fresh weight were obtained and oven dried at 70°C for 48 hours for dry matter determination. Dried samples were milled in a laboratory hammer mill (Retch Muhle, Dietz) to pass through a 1.0mm sieve. These samples were stored in airtight containers, labelled and kept in a dark cupboard at room temperature, until required for nitrogen and phosphorus content determination, according to the methods described in chapter 4, section 4.2.1.

5.2.3 Statistics

Maize grain yields observed under different management systems and across different cropping sides were analysed using the MIXED methods of SAS (Little *et al.,* 1996). Differences in treatment means were compared using the Sed value at the 5 % significance level.

5.3 Results

5.3.1 Soil chemical properties

Chemical properties of soil sampled at depths 0cm to 10cm at the start of the experiment have already been presented (cf. chapter 3, Table 3.1). Results for 2001 and 2002 are presented in Table 5.1 and Figure 5.1. Results indicate that there was no significant (P>0.05) differences in pH, organic carbon, total nitrogen, potassium, sodium, soil acidity and effective cation exchange capacity, due to the cultivation of the selected herbaceous legumes in 2001 (Table 5.1). Similar analysis for 2002 also showed no significant (P>0.05) difference due to the selected herbaceous legumes and the data are therefore not shown. However, there were significant differences in soil pH and soil nitrogen due to rotational treatments (1yrL2yrM and 2yrL1yrM) planted with maize in 2002 (Fig. 5.1). In contrast, organic carbon levels and effective cation exchange capacity were significantly (P< 0.05) different only where maize followed two years of legumes (Fig 5.1). In general, higher pH, soil nitrogen and ECEC values were found for *M3* systems, where maize residues were removed, fed to small ruminants and manure returned to the soil, compared to management systems *M1* and *M2,* where maize residues were either left in the fields or removed to be used elsewhere. In the case of soil organic carbon, no differences were found between management systems *M1* and *M2*, but lower values were found where the residues were removed to be used elsewhere, i.e. under management *M2*.

Table 5.1 Soil properties at 0 - 10 cm depth after one year of legume fallow in the northern Guinea savannah, 2001.

	pH	N	OC	C:N	P	Ca	Mg	K	Na	$Al^{++} + H^{+}$	Mn	ECEC
	H_2O	← $g\ kg^{-1}$ DM →			$\mu g\ g^{-1}$	← C mol kg^{-1} →						
A. histrix	5.1	0.89	7.9	98.9	5.82	2.14	1.08	0.54	0.31	0.0025	0.074	4.44
C. pascuorum	5.3	0.82	8.9	111.8	7.22	2.47	1.07	0.53	0.37	0.0039	0.082	4.49
S. guianensis	5.3	0.88	7.6	101.5	8.66	2.93	1.35	0.63	0.35	0.0050	0.088	5.47
A. hypogaea	5.3	0.88	7.8	92.7	6.94	2.58	1.23	0.60	0.39	0.0025	0.084	5.06
G. max	5.2	0.83	8.5	97.1	7.80	2.45	1.21	0.56	0.3	0.0025	0.100	4.83
V. unguiculata	5.2	0.75	7.9	108.9	7.13	2.35	1.15	0.50	0.28	0.0016	0.071	4.72
Natural vegetation	5.3	0.85	8.5	108.4	5.66	2.78	1.22	0.56	0.37	0.0033	0.076	5.33
Sed ±	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = Not significant at P = 0.05

ECEC = Effective cation exchange capacity
C:N = carbon to nitrogen ratio

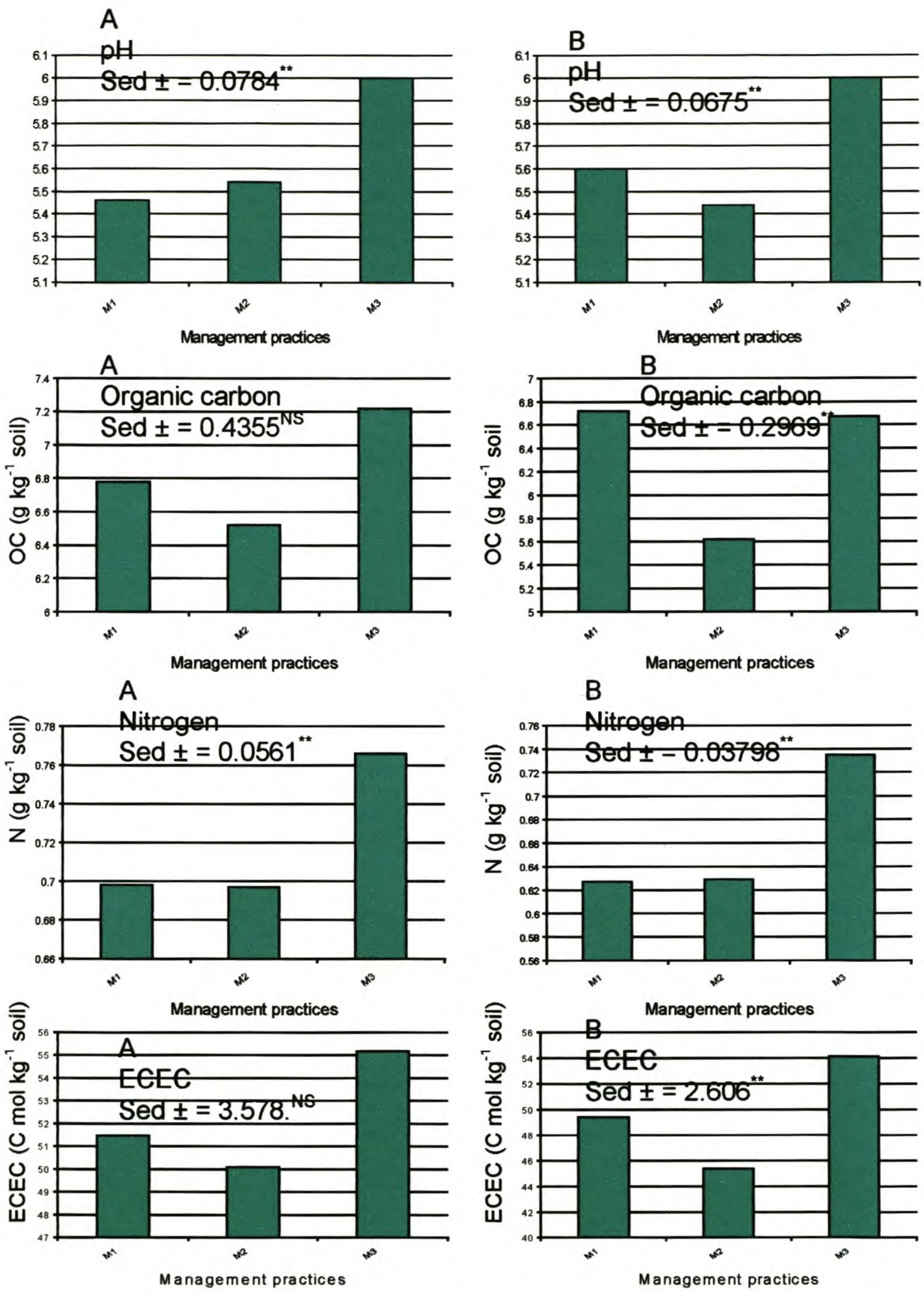


Figure 5.1 Soil chemical properties at 0cm to10 cm in 2002 in the northern Guinea savannah in two rotational cropping systems A and B.

A) rotation system=one-year fallow followed by two years of maize cropping, 1yrL2yrM
B) rotation system= two-year fallow followed by one year of maize cropping, 2yrL1yrM
ECEC= effective cation exchange capacity.

5.3.2 Crop response after varying lengths of herbaceous legume fallow and between localities

5.3.2.1 Main experiment in the northern Guinea savannah

Plant height

Monthly maize plant height measurements after one year of fallow with herbaceous legumes in 2001 did not show any significant (P>0.05) interaction as a result of legume species used and management systems (Fig 5.2a). Similar results were found for both rotational systems in 2002 (Fig 5.2b,c).

Grain and stover yields

Maize grain and stover yields in 2001 on plots fallowed for one year with herbaceous legumes are presented in Figures 5.3 and 5.4. In terms of grain yield in 2001, significant interactions between legume species and management systems were found (Fig. 5.3b). Maize produced more grain in *A. histrix* plots under the *M1* management system, but under *M2* and *M3* management systems, maize grown on *S. guianensis* plots produced the most grain. Although not significant, *S. guianensis* produced on average slightly more grain compared to the other legumes tested, while *M3* also produced slightly higher yields. Significant interactions (P < 0.05) existed between the herbaceous legumes and the management systems in terms of dry matter yield of maize stover (Fig 5.4b). In management system *M2*, the highest stover yield was, surprisingly, found after natural vegetation, but in management system *M3*, higher stover yields were found after grain legumes (*A. hypogaea, G. max* and *V. unguiculata*). Little difference was found between the legume species in management system *M2*, although it appears as if the forage species resulted in a marginally higher maize stover yield.

Results of maize grain and stover yield for 2002 in two different rotational systems are presented in Figures 5.5 to 5.8. Significant interactions ($P<0.05$) between legume species and management systems occurred in rotational system 1yrL2yrM in terms of maize yield (Fig. 5.5b). Natural vegetation and *G. max* resulted in the highest maize grain yield in management system *M3*. *G. max* and *A. histrix* had the highest grain yield in *M2* and *A. histrix* and *S. guianensis* the highest grain yield in management system *M1*. For this reason, no clear trends could be observed.

With regard to stover yield, no significant interactions or differences between main treatments ($P>0.05$) were found in this rotational system, where two years of legume fallow were followed by 2 successive years of maize (Fig. 5.6).
In the rotational cropping system 2yrL1yrM, there were again significant interactions ($P>0.05$) between legume species and management systems in terms of grain yield (Fig 5.7b). *A. hypogaea* and *G max* resulted in the highest grain yields in all three management systems, but the variation in the effect of the three forage legumes under the different management systems probably caused the significant interactions. On average, however, legume species did not differ

significantly (Fig. 5.7a), while management systems *M1* and *M3* out yielded system *M2*.

As far as maize stover yields are concerned, there was no significant interaction and no significant differences between legume species (Fig. 5.8a,b), but management systems *M1* produced significantly higher stover yields compared to systems *M2* and *M3* (Fig. 5.8c).

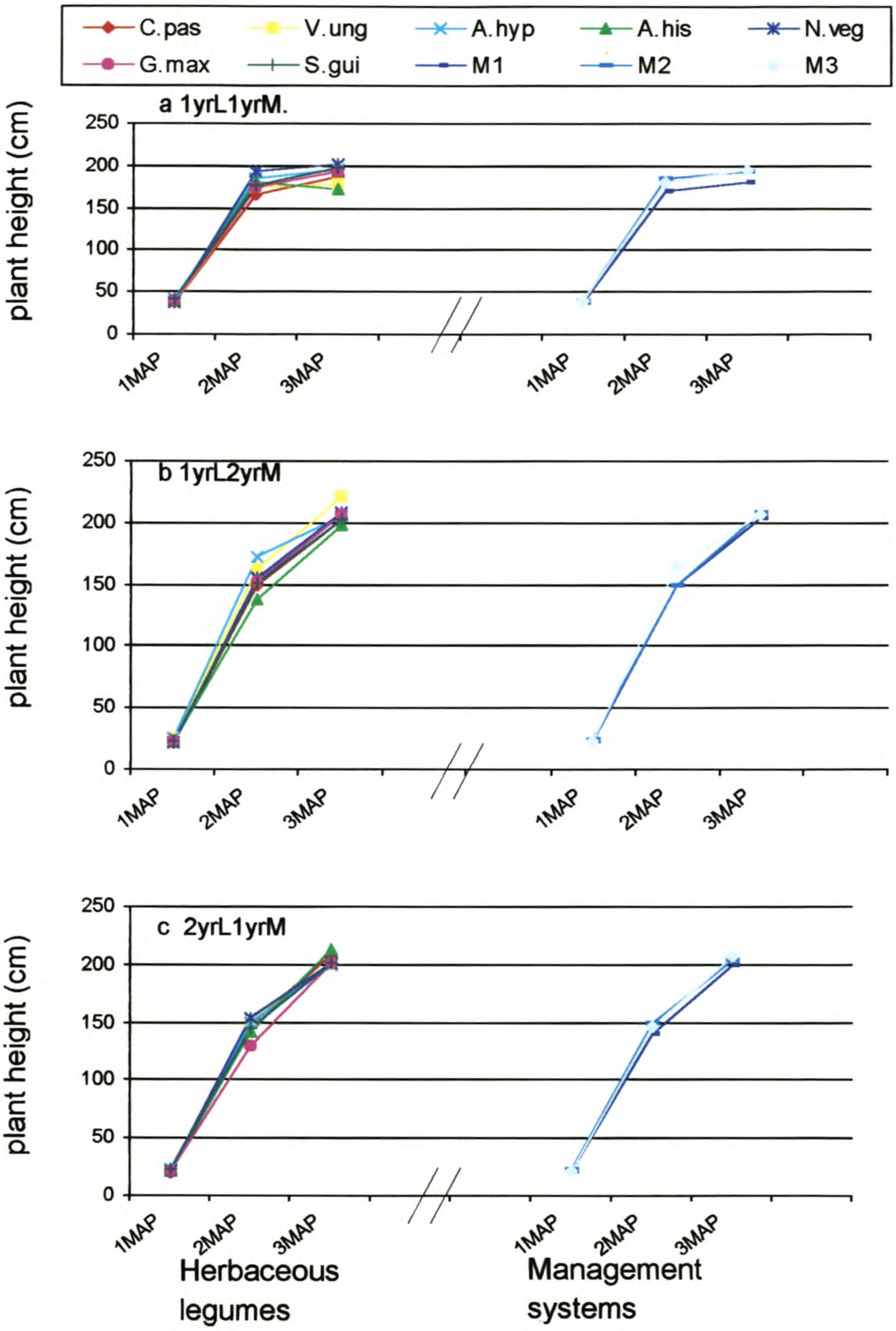


Figure 5.2 Mean maize plant height in different rotational systems as influenced by legume species and management systems in the main experiment in the northern Guinea savannah.

a) Maize in 2001 after one year of legumes in 2000
b) Maize in 2002 after one year of legumes in 2000 and one year of maize in 2001
c) Maize in 2002 after two years of legumes in 2000 and 2001

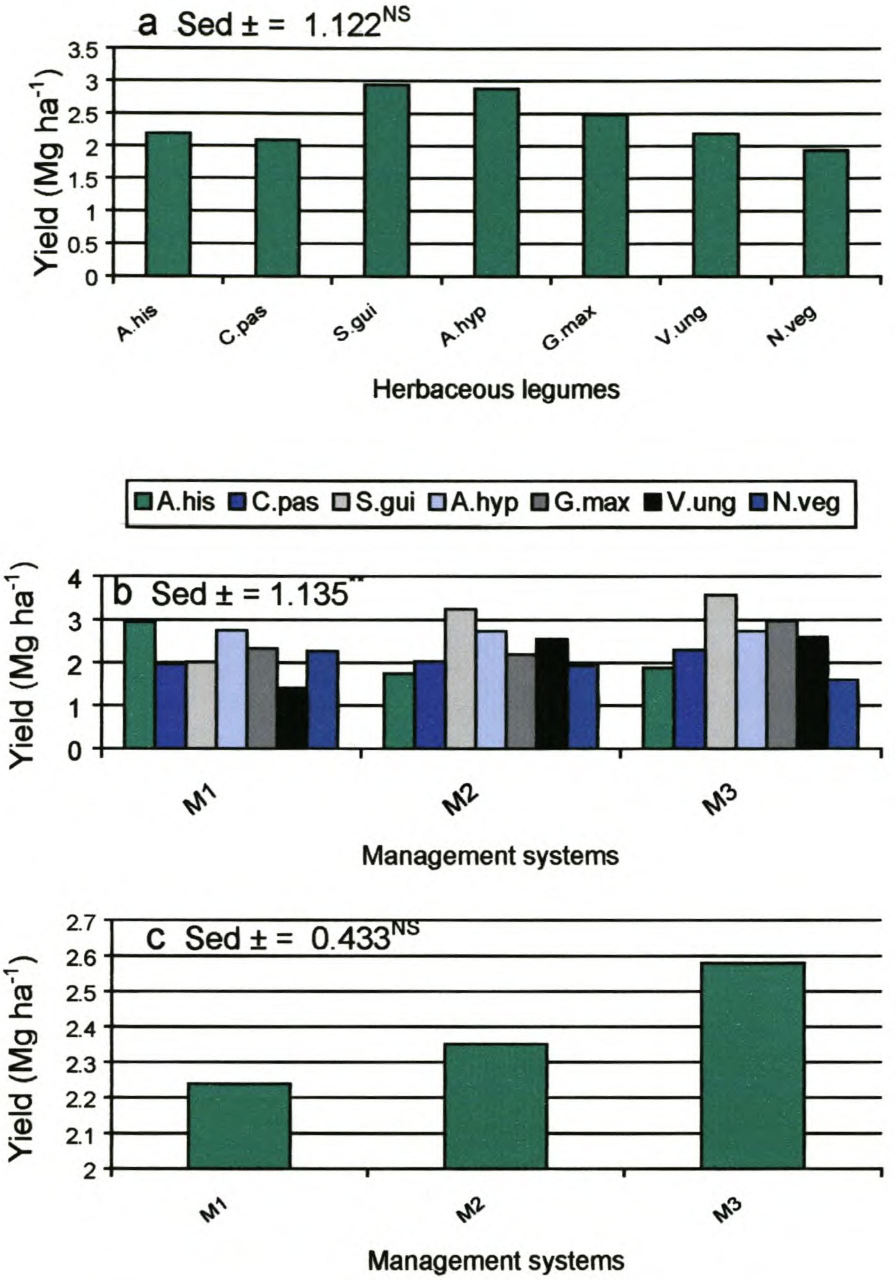


Figure 5.3 The effect of legume species and management systems on maize grain yields in 2001 after legumes in 2000 in the main experiment in the northern Guinea savannah, 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung= V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

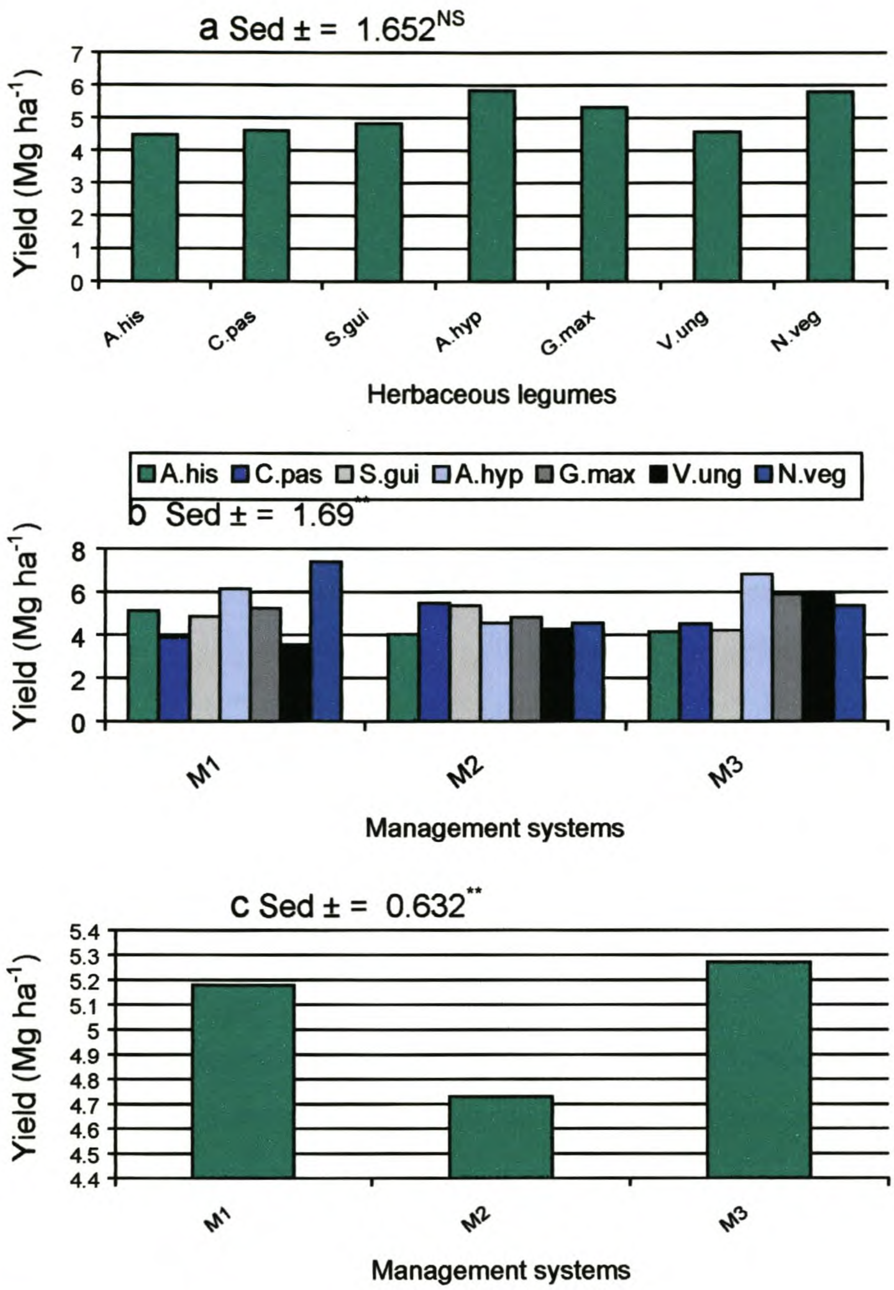


Figure 5.4 The effect of legume species and management systems on maize stover yields in 2001 after legumes in 2000 in the main experiment in the northern Guinea savannah, 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

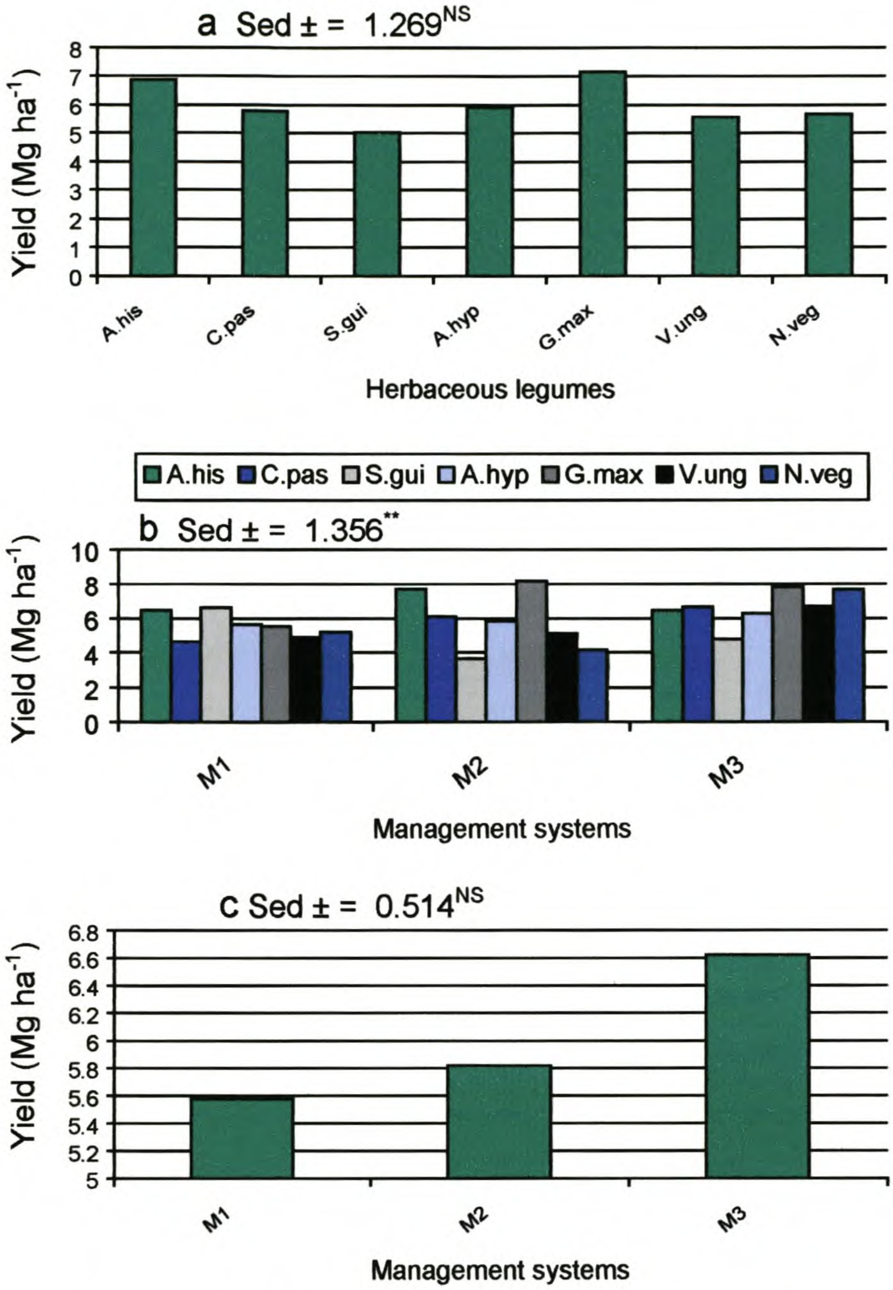


Figure 5.5 The effect of legume species and management systems on maize grain yields in 2002 after legumes in 2000 and maize in 2001 in the main experiment in the northern Guinea savannah, 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

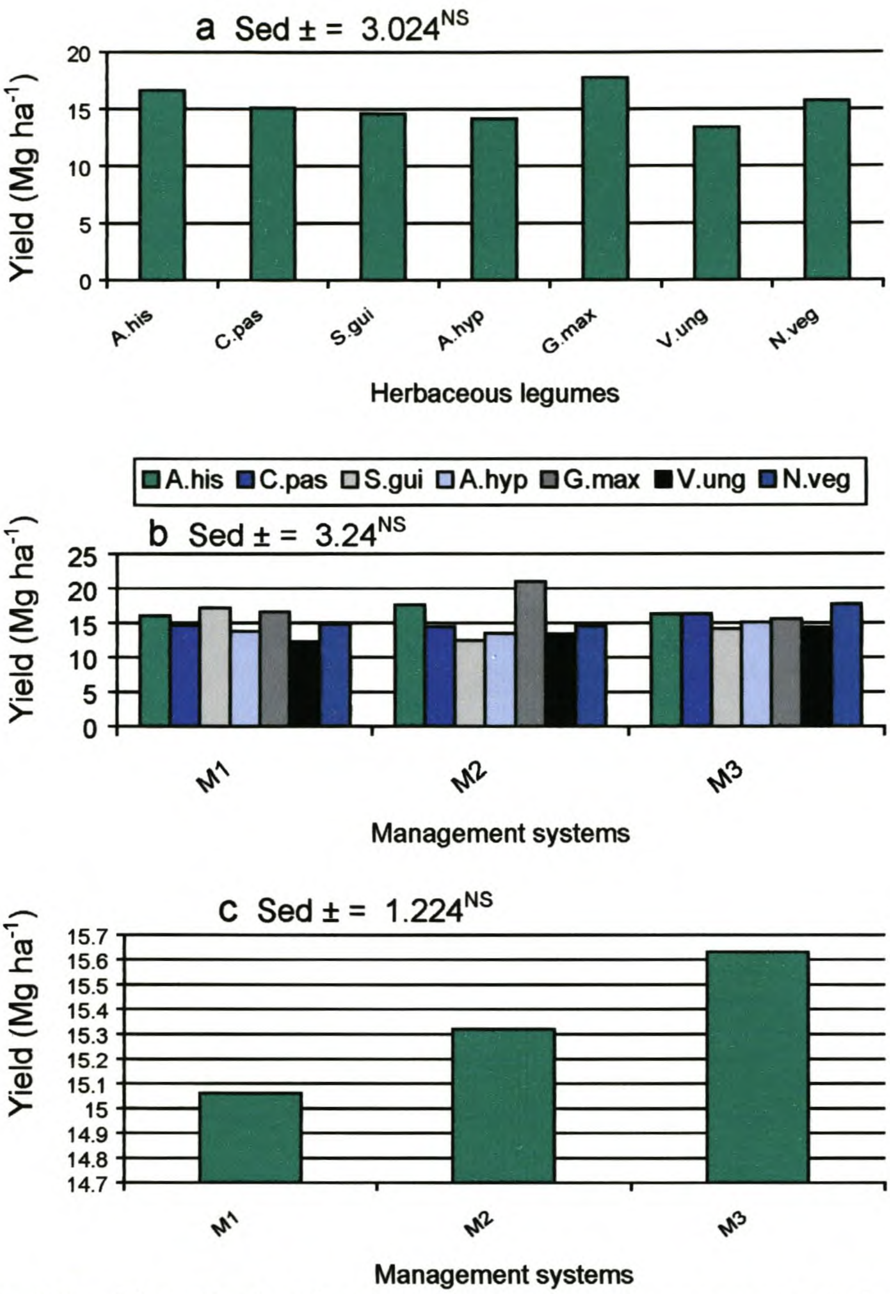


Figure 5.6 The effect of legume species and management systems on maize stover yields in 2002 after legumes in 2000 and maize in 2001 in the main experiment in the northern Guinea savannah, 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

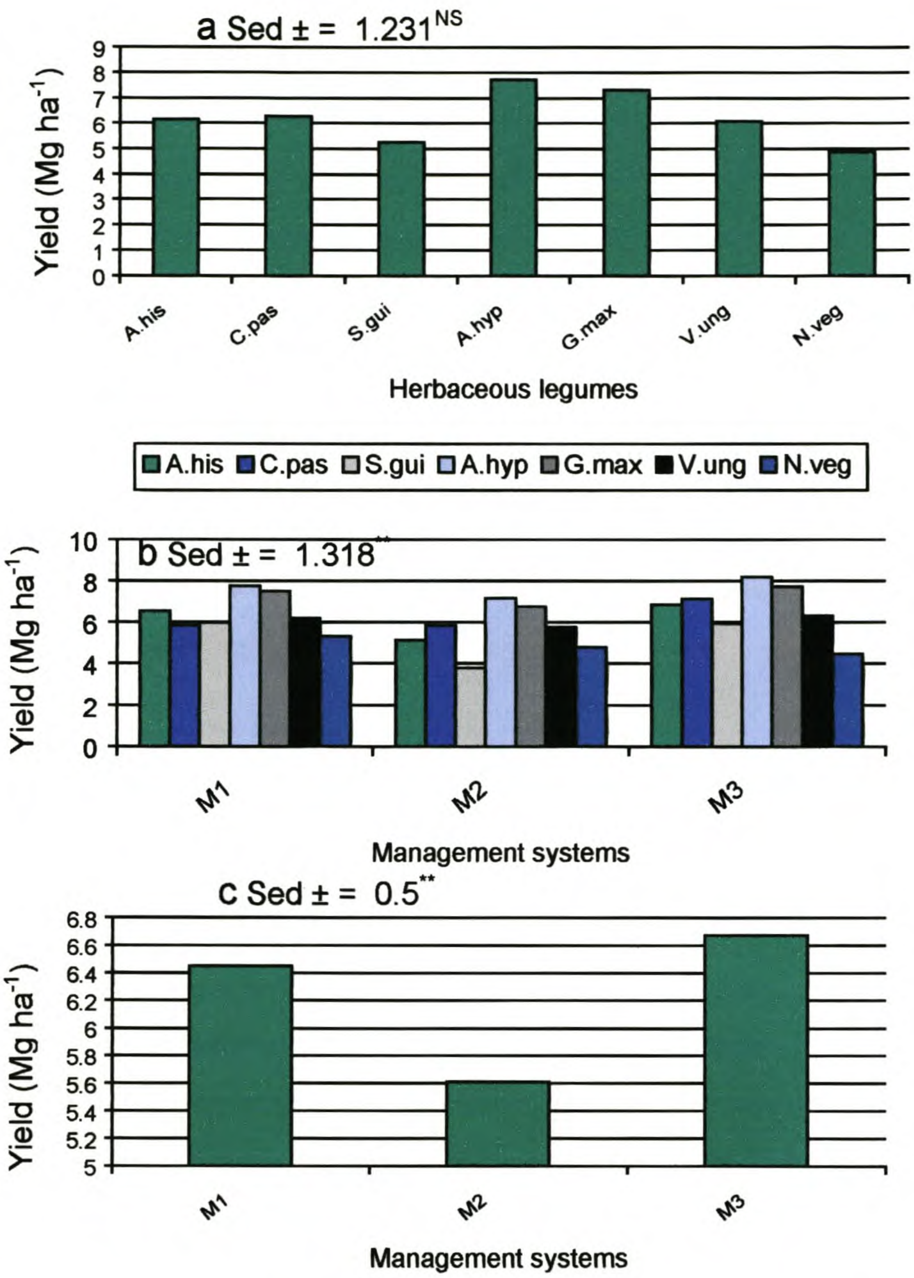


Figure 5.7 The effect of legume species and management systems on maize grain yields in 2002 after legumes in 2000 and 2001 in the main experiment in the northern Guinea savannah, 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

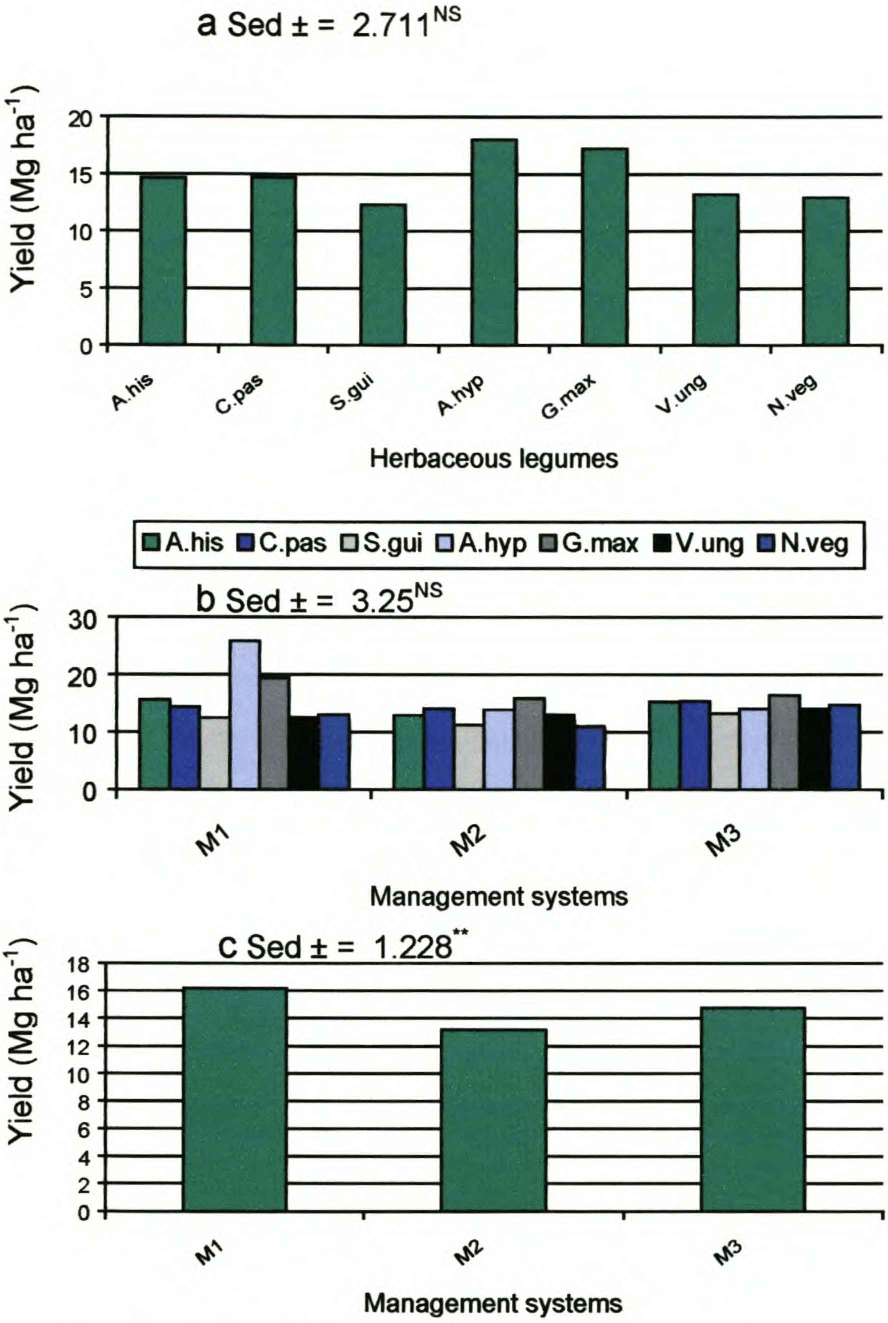


Figure 5.8 The effect of legume species and management systems on maize stover yields in 2002 after legumes in 2000 and 2001 in the main experiment in the northern Guinea savannah, 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

5.3.2.2 Secondary experiments in the northern Guinea savannah and derived savannah

Northern Guinea savannah scenario

Results on maize grain and maize stover yields in the northern Guinea savannah were very similar to those of the main experiment, but no significant interactions between legume species and management systems or between main treatments (legume species) and management systems were found. For this reason, results are not shown.

Derived savannah scenario

Maize plant height measurements in the derived savannah are presented in Figure 5.9. Results showed that maize plants generally grew higher in the derived savannah (Fig. 5.9), compared to the northern Guinea savannah (Fig. 5.2). This could be because of climate and soil conditions, or because of the different cultivars planted. Significant interactions ($P<0.05$) occurred with regard to plant height between the natural vegetation and the herbaceous legumes tested and time after planting. This was due to the sharp decrease in maize plant height grown after natural vegetation between measurements at the end of four months after planting.

No significant (P>0.05) effects due to legume species (Fig. 5.10a) or interactions between legume species and management systems in terms of maize grain (Fig. 5.10b) were found. But significant differences did occur due to the effect of management systems (Fig. 5.10c). Surprisingly, management system *M2,* where the legumes residues are removed from the field, resulted in significantly higher maize grain yield than management system *M1,* where the residues stay on the field.

With regard to maize stover production, legume species had no effect (Fig. 5.11a), but significant interaction between legume species and management systems occurred. *V. unguiculata* resulted in the highest maize stover production in management system *M1,* but the second lowest stover production in management system *M2* (Fig. 5.11b). As found for grain yields, management system *M2* also produced more stover compared to management system *M1* (Fig. 5.11c).

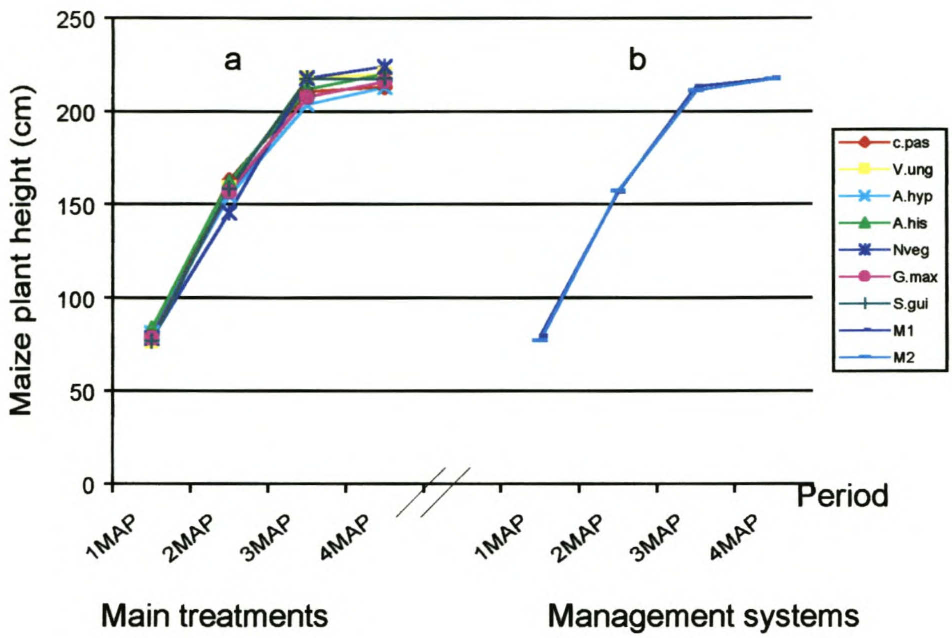


Figure 5.9 Maize plant heights at different periods after planting as influenced by (a) legume species and (b) management systems in the secondary experiment in the derived savannah, 2002.

***Abbreviations:** A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field.*

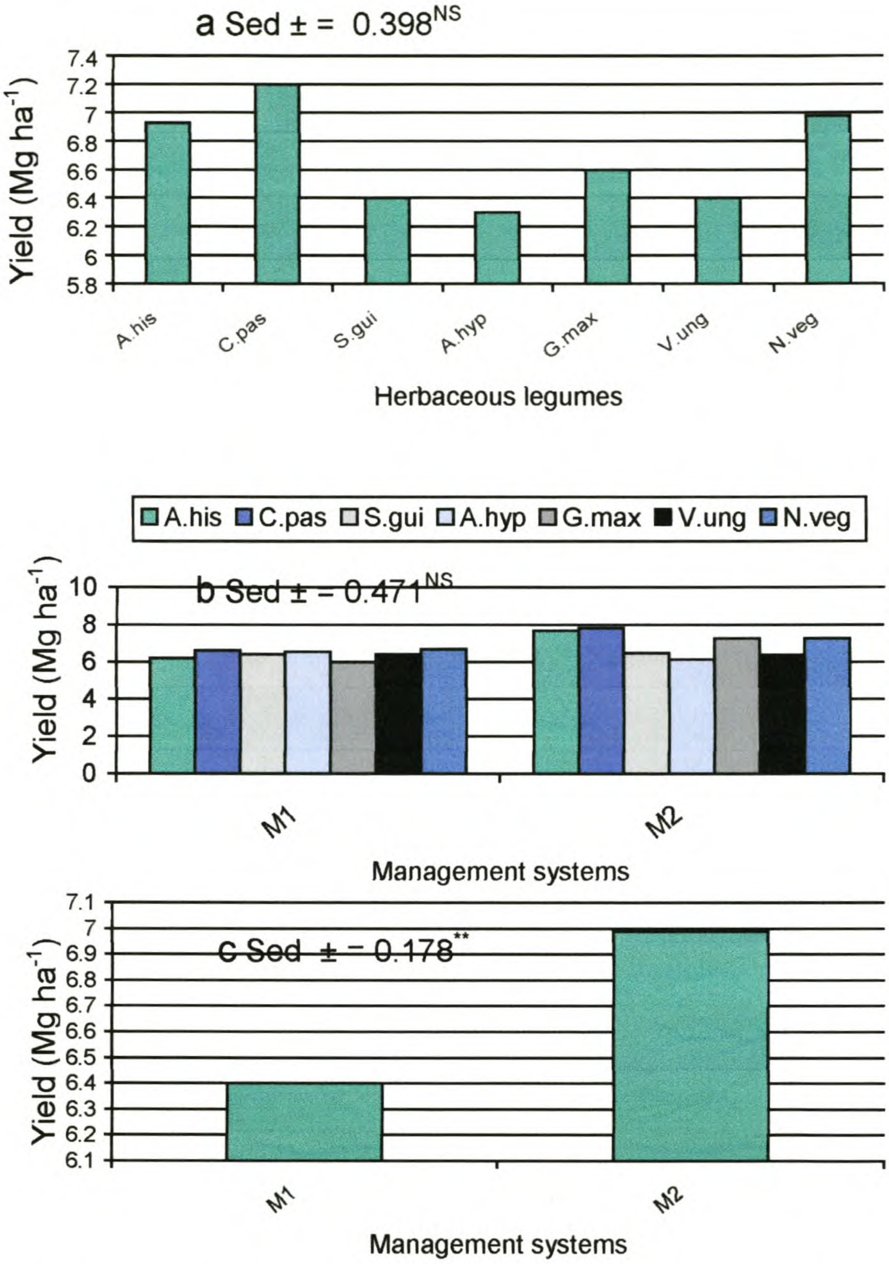


Figure 5.10 Maize grain yields as affected by legume species and management systems in the secondary experiment in the derived savannah, 2002.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field.

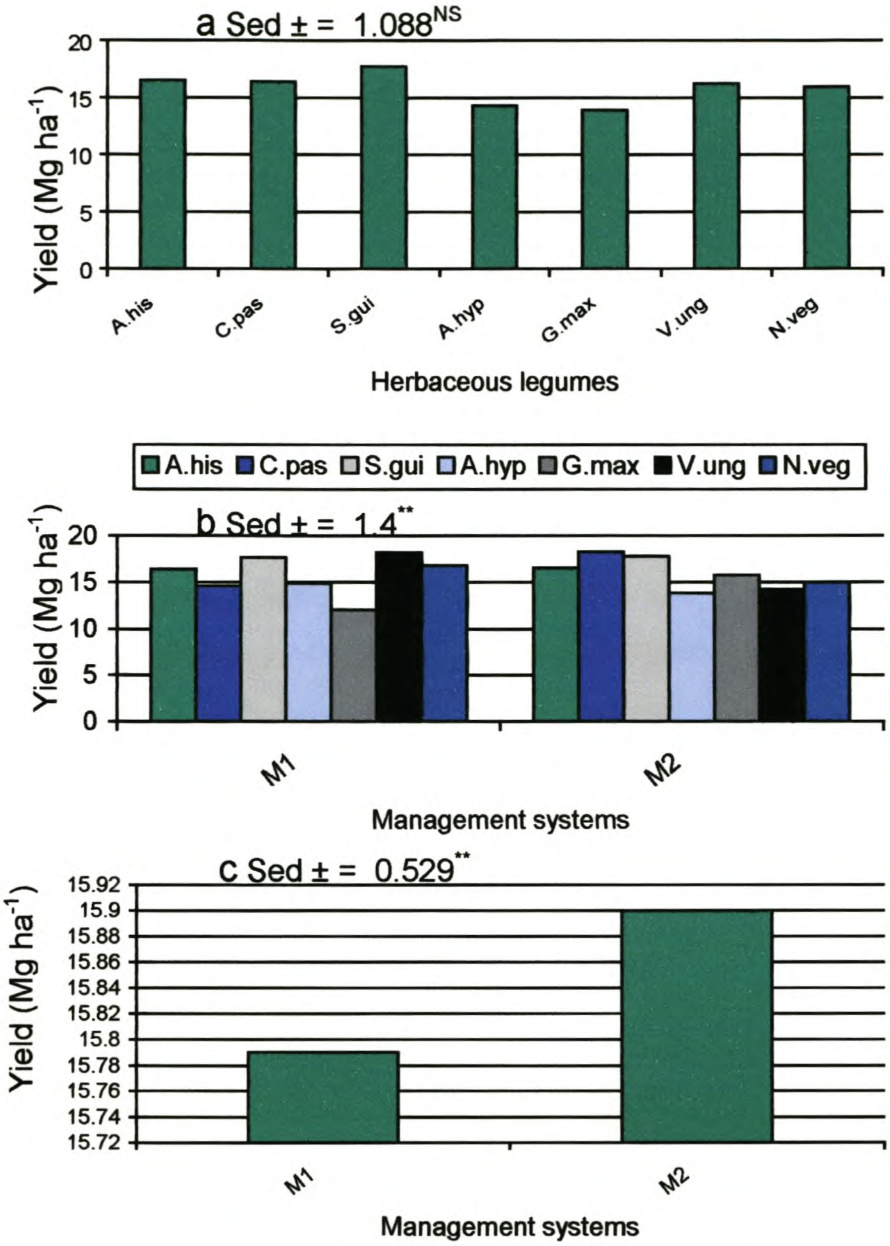


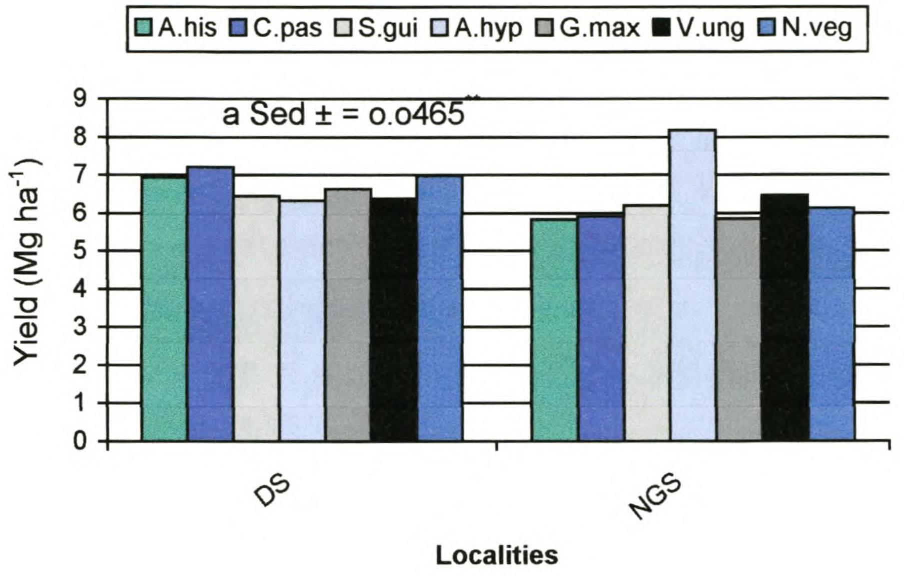
Figure 5.11 Maize stover yields as affected by legume species and management systems in the secondary experiment in the derived savannah, 2002.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field.

5.3.2.3 Comparison between localities

Maize plant height measurements across the two localities showed higher maize plants in the derived savannah than in the northern Guinea savannah. The growth rate during the first month of planting showed a steady growth of about 75cm in the derived savannah, but a rather stunted height of 30cm per stand was observed in the northern Guinea savannah within the same period (Figs. 5.2 and 5.9). However, at harvest the differences were not that great.

Results for maize grain and stover yields from the two localities are presented in Figures 5.12 and 5.13. There was significant interaction between legume species and localities (Fig. 5.12a). *A hypogaea* appeared to have a significantly higher positive effect on maize grain yield in the northern Guinea savannah, whereas there were no big differences between species in the derived savannah. Maize grain yield appeared to be marginally higher in the derived savannah than in the northern Guinea savannah (6.7 vs 6.35Mg ha^{-1}) (Fig. 5.12b). In contrast, dry matter yield of maize stover was higher in the northern Guinea savannah than in the derived savannah (Fig. 5.13b). However, the same significant interaction occurred where *A. hypogaea* and also *C. pascuorum* had a more positive effect on stover yield in the northern Guinea savannah, whilst in the derived savannah, *S. guianensis* appeared to have a more positive effect than the other species. Of interest is that the natural vegetation in the derived savannah appeared to have more or less the same effect on maize grain and stover yield as most of the legume species.



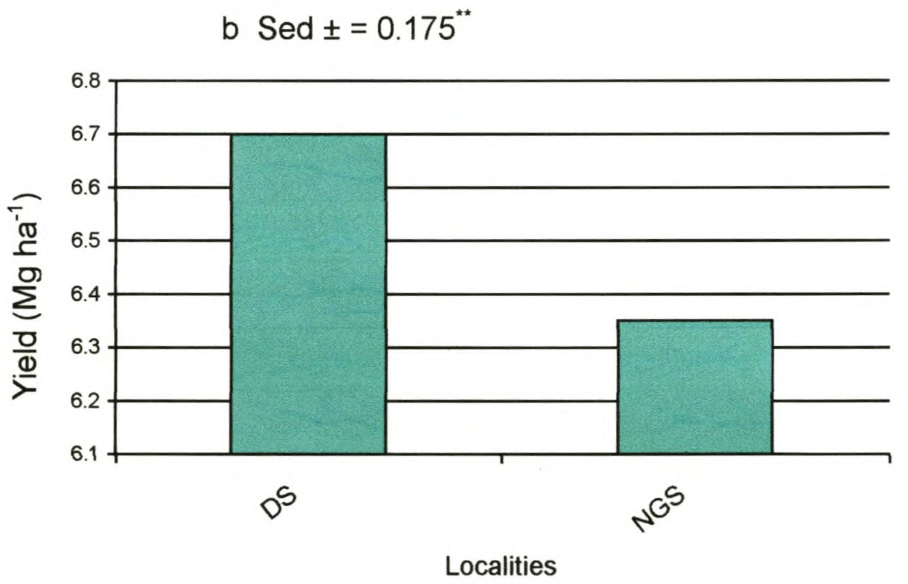


Figure 5.12 The effect of locality and legume species on the grain yield of maize in the secondary experiment in the derived savannah in 2002.

a) Interaction between legume species and location, b) performance in each location.
DS = Derived savannah, NGS = Northern Guinea savannah.

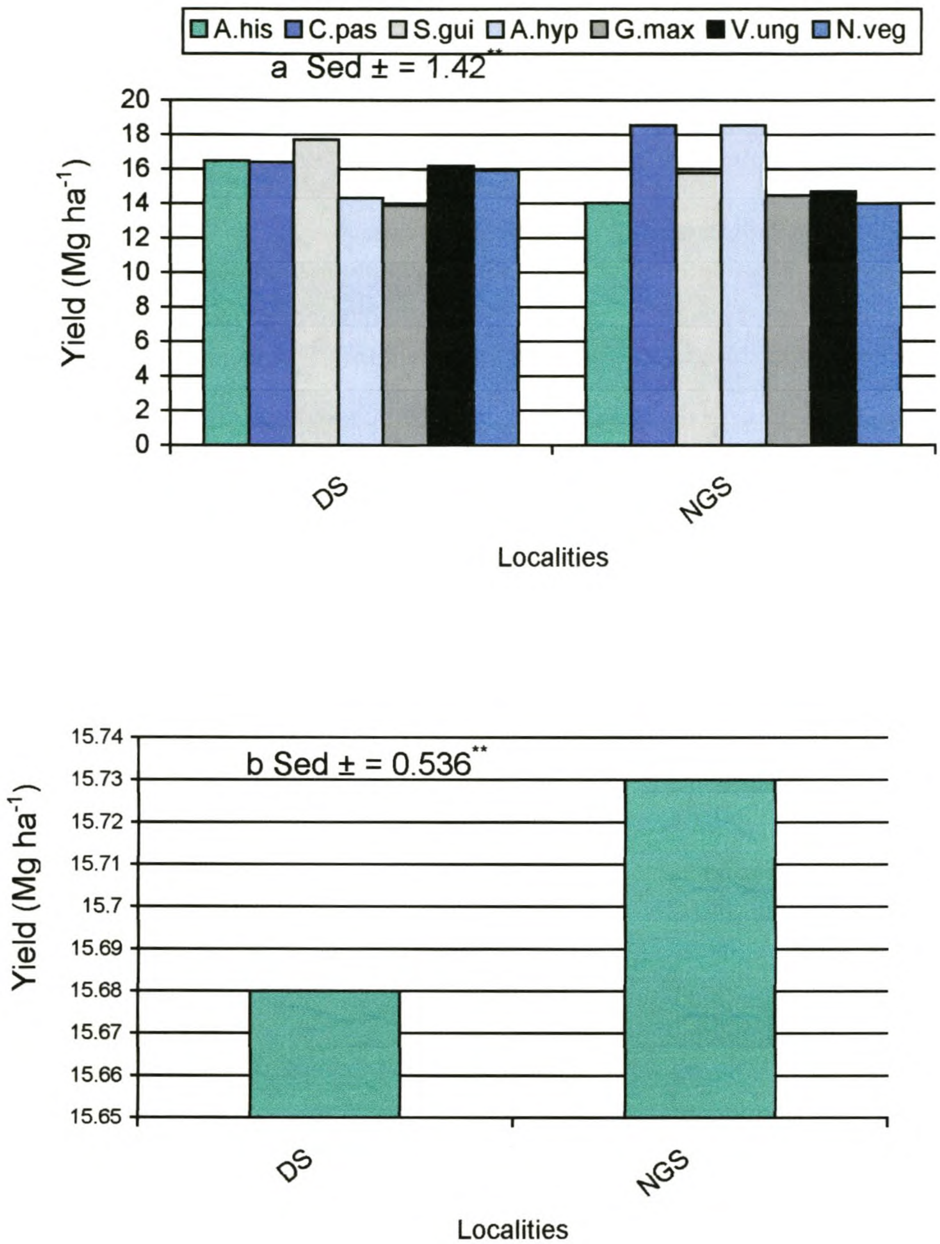


Figure 5.13 The effect of locality and legume species on the stover yield of maize in the secondary experiment in the derived savannah in 2002.

a) Interaction between species and location, b) performance in each location.
DS = Derived savannah, NGS = Northern Guinea savannah

5.4 Discussion

5.4.1 Soil chemical properties and legume interaction

The contribution of legumes to soil nitrogen, and to a subsequent cereal crop, depended on the capacity of the legumes to fix atmospheric nitrogen, the nitrogen accumulation in the crop (and recycled to the soil), its root mass and also the purpose for which the crop was grown, i.e. for grain, forage or green manure (Oikeh *et al*., 1998). For soil sampled after one year of legume fallow, non-significant values observed could be attributed to the short duration of the legume fallow. However, significant differences for soil pH, organic carbon, nitrogen and ECEC after two years of legume fallow were caused by the management systems, and not by the legumes species *per se*. Therefore, in the context of this study, nitrogen fixation was estimated through a system that simulates a situation identical to that which farmers normally practice.

In both rotational systems investigated, it is clear that management system *M3*, where compost was returned to the field, had the most positive effect on soil characteristics. The only parameter where management system *M1,* crop residue left on the field, had a comparative effect was in the *2yrL1yrM* rotational system, where the effect on organic carbon content of the soil was similar to that of management system *M3*. Irrespective of the results of this analysis, studies had indicated that maize yield differences following legume pastures cannot be entirely explained by soil characters, especially total nitrogen (Mohammed-

Saleem & Otsyina, 1986; Tarawali, 1994). Therefore, measuring nutrients in soil may not say much *per se*, and measuring maize yields could not only be more informative, but may also be related to farmers' circumstances and actions (Tarawali & Peters, 1996).

5.4.2 General observation on maize yield response across treatments and localities

Results of the effects of legumes on subsequent maize and management systems have been presented. It is noteworthy that the experiment was not designed to assess economic implications of research findings in this study, however, maize performance and forage dry matter yield could give indication of an economic value of legume species and management systems tested in the system.

Climatic conditions varied between the two sites. The northern Guinea savannah is characterised by a shorter growing period of 151 to 180 days, whereas the derived savannah has a longer period of between 211 to 270 days (Jagtap, 1995). These variations could contribute to the differences observed in growth rate and maize yields. For instance, the lower dry matter yields of maize in the northern Guinea savannah, compared to the derived savannah after one year of fallow, could be attributed to insufficient supply of soil nutrients, especially nitrogen, and insufficient rainfall.

5.4.2.1 Main experiment in the northern Guinea savannah

Herbaceous legumes evaluated within the framework of the three management systems in the present study illustrated the potential of legumes tested to improve subsequent crop production by improving soil fertility. The occurrence of interactions complicates the interpretations of the results, but in general, management system *M3* resulted in both the highest maize grain and stover yields, especially in the rotational systems where only one year of legumes was included (Figs. 5.3 to 5.6). In the management system where two years of legumes were included, management system *M1* also had a positive effect on maize grain and stover yield, compared to *M2* where crop residues were removed from the field (Figs. 5.7 to 5.8). This could probably be attributed to the fact that after two years of legumes, the nitrogen content of the soil due to nitrogen fixation by legumes was sufficient to supply crop needs. Nitrogen from animal compost in *M3* did therefore not result in any yield improvement. In contrast, with only one year of legume fallow, conversion of the organic material by ungulates into available nutrients was necessary in *M3*. The enhanced yields are therefore probably due to recycling of crop residues through the rumen of small ruminants, resulting in the combined effects of (i) urine application that increases soil pH and phosphorus availability (ii) the addition of nitrogen applied in the form of urine as well as (iii) biological nitrogen fixation by the legumes (Powell *et al.*, 1998). This is also in agreement with earlier findings by Larbi *et al.*

(2002), who showed that the total productivity of land in smallholder mixed crop/livestock systems could be improved, provided that farmers can afford the labour and transport needed to return rejected crop residues, mixed with urine and faeces and other household waste, to farmlands to restore soil productivity.

Considering the performance of individual legumes in the system in 2001, higher maize grain yields were realised on plots fallowed with herbaceous legumes, compared to the natural vegetation, although the difference was not statistically significant (P>0.05). These results confirmed earlier results of legume cropping experiments in the northern Guinea savannah (Kasasa *et al.,* 1999; Odunze, Iwuafor & Chude, 2002). The difference in grain yields between continuously cropped soil and naturally fallowed soil narrowed, but soils that were previously sown to legumes retained their advantage.

The superior effects of the returning of manure on maize grain and stover yield in management system *M3* was in agreement with the findings of Peoples, Herridge & Ladha (1995). Under these conditions, the benefits of planted legumes to a subsequent crop may encourage farmers to explore the possibility of short legume-crop rotations to provide forage banks, whereby the farmers or agro-pastoralists can assess the advantages of legumes to crop production in the northern Guinea savannah.

5.4.2.2 Secondary experiment in the derived savannah

Legume species performance in 2001 was not a significant covariant with maize yield in 2002. These results suggest that either the soil was uniform, or that blocking successfully reduced variability due to inherent soil fertility. The non-significant increase in dry matter maize grain yield, compared to natural vegetation after a one-year fallow, is in agreement with earlier findings under a short fallow rotation with legumes (Carsky, Oyewole & Tian, 1999). It is interesting to note that management systems in the derived savannah had contrasting effects compared to the northern Guinea savannah. For instance, soils with *in situ* crop residue, *M1*, generally produced higher maize grain and stover yields, than soils where crop residues were exported, *M2*, in the northern Guinea savannah. However, this trend was reversed in the derived savannah (Fig. 5.10c and 5.11c). The pattern in the derived savannah, however, might relate to the maintenance of soil nitrogen status in a more stable environmental condition. Muhr (1998) ascribed a highly significant effect on dry matter yield of maize in the major wet season to be due to a higher accumulation of nitrogen in green manure of introduced species. However, it is not clear whether long-term use of legume rotation without incorporation of leguminous residues will maintain soil fertility. It is known that allelophathic effects are more pronounced under wet conditions (Rice, 1984) and the probability that some of the legume species can have allelophathic effects on crops in the subsequent year under these conditions can not be ignored. Allelophathic interactions between herbaceous legumes and crops under these conditions are a subject that needs to be addressed.

Although differences were not significant (P>0.05), *C. pascuorum* and *A. histrix* resulted in the highest maize grain yield (Fig. 5.10a). However, this trend was not repeated with regard to stover yields. Results from this study in the derived savannah could open up criticisms and there is a need for long-term research on crop residue production and management.

5.4.2.3 Locality differences in maize yield response

In the present study, it is likely that the relatively high soil fertility status in the derived savannah, as well as a high nitrogen accumulation after fallowing with selected herbaceous legumes in the northern Guinea savannah, were responsible for maintaining yields of maize across the two localities. In general, only limited conclusions regarding the nature of site effects can be drawn from the results presented in this thesis, primarily due to different environmental conditions, different cultivars used and inherent soil nitrogen status. However, the experiment demonstrated the significant role of selected herbaceous legumes under varying fallow lengths and management systems for improving the supply of mineral nitrogen and yield of subsequent maize crop. No single legume species appeared to give consistently better results with respect to maize grain and stover yield in the northern Guinea savannah, although *A. hypogaea* and *G. max* gave consistently good results. *C. pascuorum* and *A. histrix* were promising legumes in the derived savannah. While there were no significant differences within locality, results indicate higher maize grain and stover yields in the derived savannah than in the northern Guinea savannah.

5.5 Conclusions

In the study sites of the northern Guinea savannah and derived savannah zones of Nigeria, legume fallow prior to subsequent maize cropping can be used to reduce fertiliser nitrogen requirements due to high levels of biological nitrogen fixation. The incorporation of compost into soil has far reaching implications for the farming systems in the northern Guinea savannah. In the northern Guinea savannah, it may, however, be more appropriate to feed the legumes to livestock and carry the compost back to the fields. Although this was not investigated in the derived savannah, it is a feasible alternative in this zone as well. In 2001, i.e. after a one-year fallow with legumes, dry matter maize grain and stover yields for *S. guianensis* were higher among the forage legumes, while *A. hypogaea* gave the best performance among the grain legumes in the northern Guinea savannah. Results in 2002, i.e. after a two-year fallow, also indicate the productivity of maize planted on *A. hypogaea* and *G. max* fallowed plots to be consistently higher across the three management systems tested in the northern Guinea savannah. For the derived savannah, soils fallowed with *C. pascuorum* and *A. histrix* with the management system that had no crop residues, *M2,* gave the best overall performance.

While there are many constraints impeding a sustainable cropping approach in the two localities under study, future research focus should include (i) a search for more suitable varieties of leguminous species, (ii) nutrient budgeting and cycling studies and of course (iii) economic and impact assessments of the research findings.

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Chapter 6

Weed dynamics

6.1 Introduction

The weed infestation in a field is defined by three parameters: 1) the number of species present, 2) the density of each species, and 3) the distribution of the species across the field. While the number of species in a field remains relatively constant from year to year, the latter two factors fluctuate widely in response to environment, cultural practices, and weed management practices. It is the continual changes in weed infestations that make successful weed control such a difficult task to achieve consistently (Hartzler, 2000).

The weed seed bank has been recognised as the driving force for weed infestation in arable fields. In agricultural fields, this is made up of many species, but in any given year the infestation typically is dominated by a few species (Kamara *et al.*, 1999). After the traditional fallow phase, the weed seed population in the soil may be so depleted that when the bush is cleared, weeds are usually not a problem in the first year of cultivation (Akobundu, Ekeleme & Agyakwa, 1992).

Legume-based contributions to the sustainability of intensified systems have been recognised for a long time (Sanginga *et al.,* 1996; Carsky *et al.*, 1998; Schulz, Carsky & Tarawali, 2001). An additional feature of legumes in cropping systems is their ability to suppress weeds, thereby alleviating weeding stress faced by farmers (Barberi, 2001). Weed growth has been suppressed in alley cropping by canopy closure (Gichuru, 1991). Kamara *et* *al.* (1999) also found the suppression of weeds by mulch application to be more effective in the presence of mulch that decomposes slowly. In addition to physical suppression of weeds, the decomposition of plant residues can also release chemical compounds that may inhibit or promote crop and weed growth (Akobundu, 1987). In such instances, weed species' richness and diversity in an ecosystem is therefore influenced by the differential response of the weeds to the chemical compounds. Some weed seeds can remain viable for long periods waiting for the appropriate stimuli from crop plants and/or their post harvest residues. This paper is part of the holistic studies to evaluate the potential of herbaceous legumes for sustainable weed dynamics, soil fertility and livestock management interactions. The present report, therefore, aimed to analyse the size and composition of seed banks, density and weed incidence as affected by the selected herbaceous legumes and management systems in the system.

6.2 Materials and Methods

This study was conducted in the main and secondary experiments in the northern Guinea savannah, but no weed survey was carried out in the secondary experiment in the derived savannah. The original design of the experiment was maintained and reported in the earlier chapters. Main plot and sub-plot treatments are also described (cf. chapter 4, section 4.2; Tables 4.1 and 4.2). Weed distribution, composition and dry mass production in the herbaceous legumes, namely: *V. unguiculata*, *A. hypogaea, G. max*, *A. histrix, C. pascuorum, S. guianensis,* natural vegetation as well as in maize plots were evaluated.

6.2.1 Dry mass production

Initial data was taken by destructive sampling of weed biomass produced in the herbaceous legume plots during 2001. Quadrates of 1m X 1m were placed into the legume plots, at least one meter away from the edge to eliminate border effects at planting, as well as one, two and three months after planting in 2001. All weed plants were cut at 10cm above soil surface and weighed. A sub-sample of about 250g to 300g was dried in an oven at 65 °C until constant weight was reached and the dry mass was determined. The wet mass/dry mass ratio was calculated and used to calculate the dry matter production of the weeds.

After establishment of maize in 2001 and 2002, weed biomass was also determined in the maize plots for both rotations *2yrL1yrM* and *1yrL2yrM* in 2002. The maize plots were weeded directly after planting and the sampling was carried out about one-and-a-half months later. The weeds encountered, therefore, represent weeds that may have survived the weeding process, and more importantly, weeds that re-established after weeding. The sampling procedure was similar to the procedure described above for the herbaceous legume plots.

In addition, similar data was taken from unweeded micro-plots of 50cm x 50cm in the large maize plots. The micro-plots were intentionally unweeded at planting. The number of micro-plots varied according to sizes of subplot (cf. chapter 4, section 4.2); for instance, three quadrats were assigned to subplot *M1*, five quadrats assigned to subplot *M2* and seven quadrats assigned to subplot *M3* respectively. In each micro-plot, weed biomass was sampled according to the procedures described above. The period of this sampling usually coincided with the time of harvesting. After sampling in the field, weed species were coded and analysed.

6.2.2 Weed identification and count

In July and November 2001, one month after planting and just before harvesting, weed seedlings were identified and counted across the maize plots, by placing two quadrats of 50cm x 50cm randomly in each plot. At the end of the exercise in the field, weed species were coded and analysed. Weed species composition across the experimental field and locations were estimated by summing the seedlings counted for each quadrat. Estimated values were then converted to seedling density m^{-2}, based on a 50cm by 50cm sampling quadrats size. The procedure was repeated in July 2002, one month after planting in the maize plots, in rotational treatments *2yrL1yrM* and 1*yrL2yrM*. However, because there did not seem to be a large variance in species composition between the two treatments, the results for the two treatments were pooled.

6.2.1.3 Weed seed bank studies

Soil was sampled to 0cm to 10cm depth, using a soil auger precision core sampler with a retaining cylinder in 2000 and 2001. Samples were taken in legume plots one month after planting in each year. At each sampling period, eighteen random soil cores, with a diameter of 2cm = approx. 1litre, were taken from each sub plot, bulked and sub-sampled for chemical analysis. The sub-samples were air-dried and passed through a 2mm sieve to remove litter, large stones and root fragments. Seeds retained on the sieve with a diameter larger than 2mm were removed and then returned to the sieved soil. The sieved soil from each subplot was spread in three germination bowls, 13cm in diameter, to a depth of about 15mm. The bowls were then placed in a screen house to allow germination to occur. The weed seed bank in the soil was quantified using the direct germination method (Forcella, Durgan & Buhler, 1996) and was replicated three times. The soils in the germination pots were watered daily. Emerging seedling were identified, counted and removed from germination bowls weekly. The soil in the germination bowls was thoroughly mixed every two weeks to encourage weed seed germination. The experiment was terminated at the end of 12 weeks when seedling emergence ceased, as was also found by Chikoye and Ekeleme (2001). Viable and non-dormant weed seed populations in the soil in each subplot were estimated by summing the seedlings counted for each subplot over the 12 weeks. Estimated values were then converted to seedling density m^{-2}.

6.2.2 Statistics

Seasonal comparison of total weed composition and total weed seed bank between the herbaceous legumes and management systems were performed using the MIXED methods of SAS (Little *et al.*, 1996). Differences in treatment means were compared using Sed values at a 5% significance level. Proc Freq methods of SAS (Little *et al.,* 1996) were used to rank weed species abundance over the three years of this experiment in the northern Guinea savannah. The model statement used for weed biomass calculation is given in the appendix 13.

The rate of change in the seed population in the soil was determined by calculating the difference in seed numbers between years for each treatment and sub-treatment and the result was expressed as the percentage of total seed pool present in each management system.

6.3 Results

6.3.1 Weed dry matter yield (biomass) across the experimental plots

There were significant ($P<0.05$) differences in weed biomass between the selected herbaceous legume plots before planting in 2001. Fewer weeds were observed on forage legume plots compared to grain legumes and natural vegetation (Table 6.1). Weed biomass estimated during the cropping period in 2001 also declined between one and two months after planting (Fig. 6.1). These values were significantly different ($P<0.05$) from values obtained for natural vegetation. It is noteworthy that weed biomass on natural vegetation plots increased as the length of growing period increases, only to decrease after two months, when moisture was diminishing. In contrast, weeds on plots seeded with legumes *A. hypogaea* and *G. max* species decreased gradually from the onset of field establishment (Fig. 6.1).

Table 6.1 Weed biomass measured in plots of the selected herbaceous legumes before planting in the northern Guinea savannah in 2001.

Treatments	Weed biomass Mg ha^{-1}
A. histrix	4.31
C. pascuorum	3.94
S. guianensis	3.33
A. hypogaea	4.44
G. max	5.17
V. unguiculata	5.75
Natural pasture	5.81
Sed $\pm$	0.972**

Sed = standard error of difference
*** Significant differences at P=0.05*

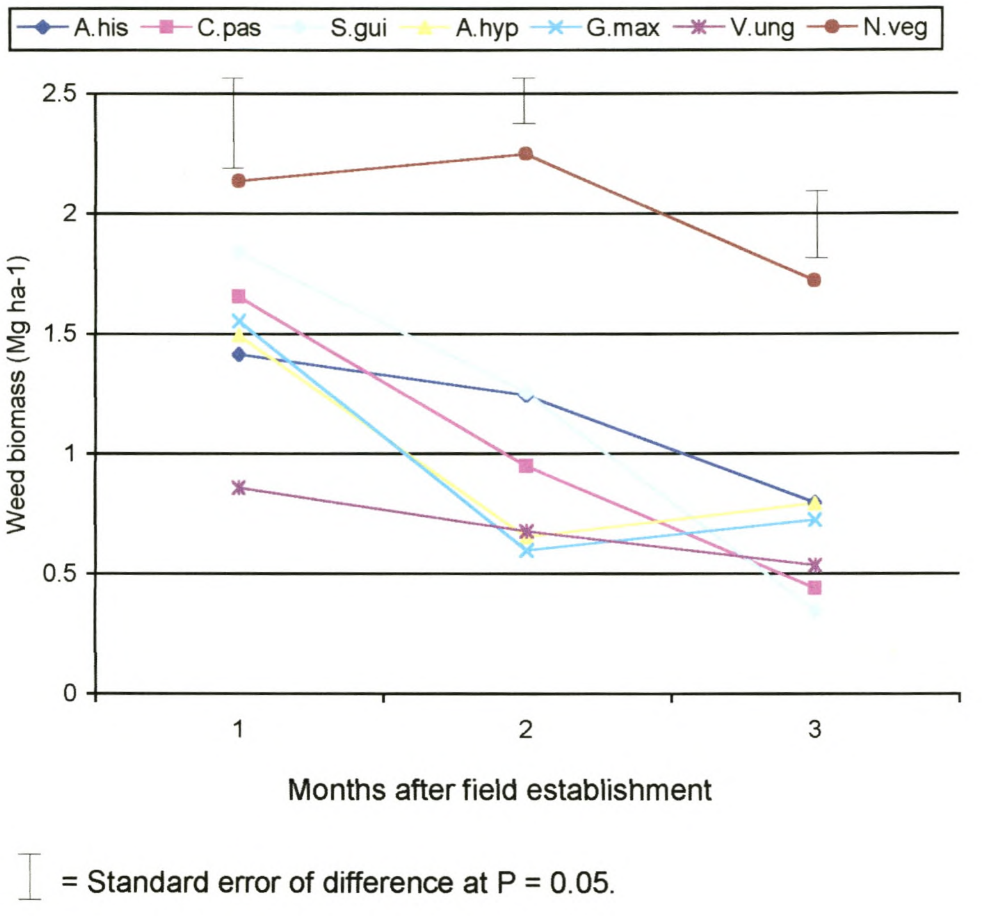


Figure 6.1 Monthly weed biomass produced under different herbaceous legume species in the northern Guinea savannah in 2001.

Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation.

Considering the result on weed biomass under maize canopies across the main plots in 2001, there were no significant (P>0.05) differences in weed dry matter yield due to the selected herbaceous legumes and management systems, or any significant interactions between the factors (Fig. 6.2). There was, however, a clear trend indicating higher weed biomass under management system *M1* than under systems *M2* and *M3* (Fig. 6.2c). However, the trend was reversed in 2002 (Fig. 6.3c). Observation on the two rotational systems[6] planted to maize in 2002, revealed that weed biomass was higher on a two-year fallowed sub-plot (Fig. 6.4), than on the one-year fallowed sub-plots (Fig. 6.3). There was significant (P<0.05) interaction between legume species and management system where two years of maize followed one year of legume fallow (Fig. 6.3b). Weeds in *S. guianensis* and *G. max* plots produced the highest biomass under management system *M1*. Whilst the highest levels of weed biomass were produced in *A. hypogaea* and natural vegetation plots in management system *M2* and in management system *M3*, the highest level of weed biomass was produced under *A. hypogaea*. The year of maize followed by two years of legume fallow showed significant differences between species and between management systems. Similarly, significant interactions existed between herbaceous legumes and management systems (P<0.05) (Fig. 6.4b). *C. pascuorum* and *V. unguiculata* had the highest weed biomass for management system *M2*, *V. unguiculata* and natural vegetation for management system *M1*. *A. histrix* and natural vegetation performed better under management system *M3*. However, only

[6] *1yrL2yrM* = one-year fallow with selected herbaceous legumes, followed by two years of maize cropping
2yrL1yrM = two-year fallow with selected herbaceous legumes, followed by one year of maize cropping.

natural vegetation had the highest weed dry matter under management system *M1*.

6.3.2 Weed dry matter yield (biomass) from micro-plots

Weed biomass from micro-plots placed randomly across the main plot treatments showed no significant interactions (P>0.05) or differences between the herbaceous legumes and management systems (Fig. 6.5). The only striking feature was the control of weed infestation across the two rotation treatments planted to maize in 2002. The data indicated that, although not statistically significant, one year fallowed with legume rotation produced more weed biomass than the rotation with a two-year fallow with legumes. More weeds were also observed for *A. histrix, C. pascuorum* and natural vegetation plots compared to the other treatments. None of these differences, however, were statistically significant (P > 0.05) (Fig. 6.5).

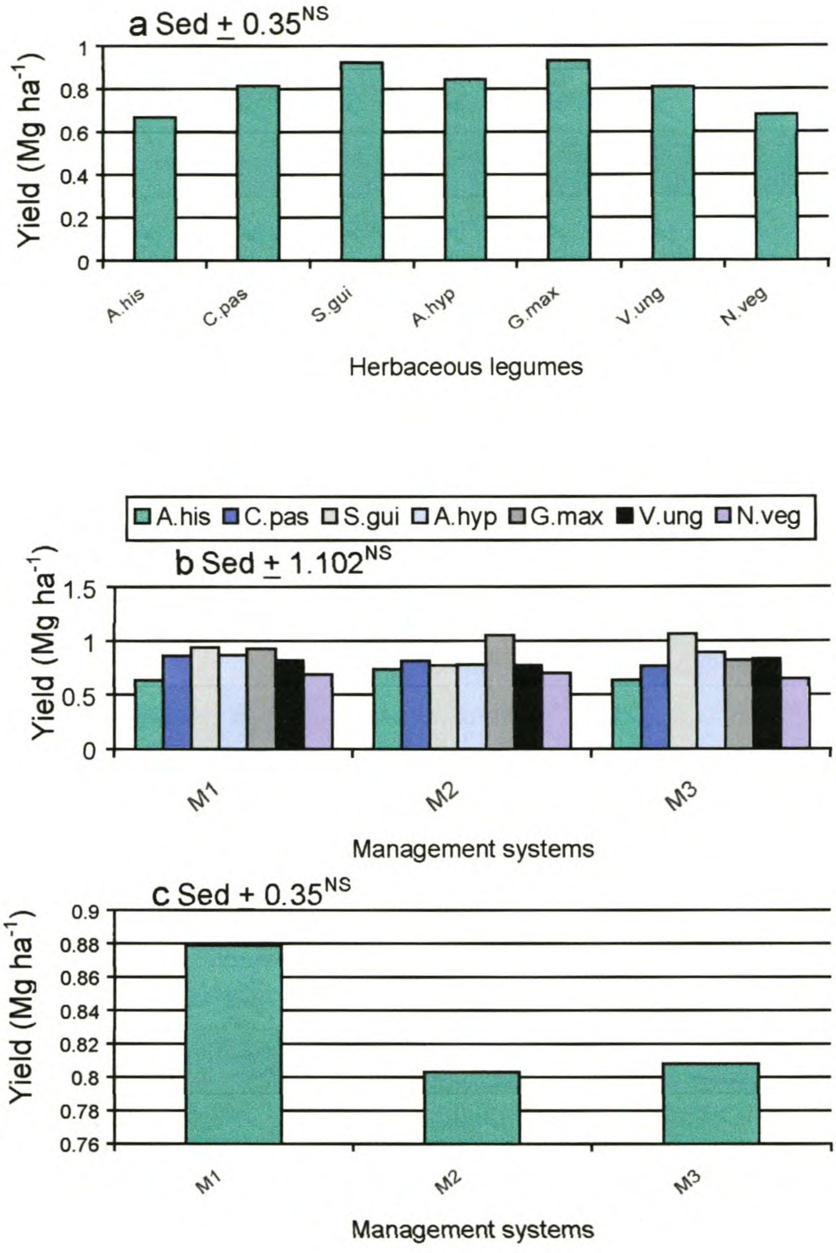


Figure 6.2 The effect of legume species and management systems on weed biomass under maize canopies in 2001.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems. Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

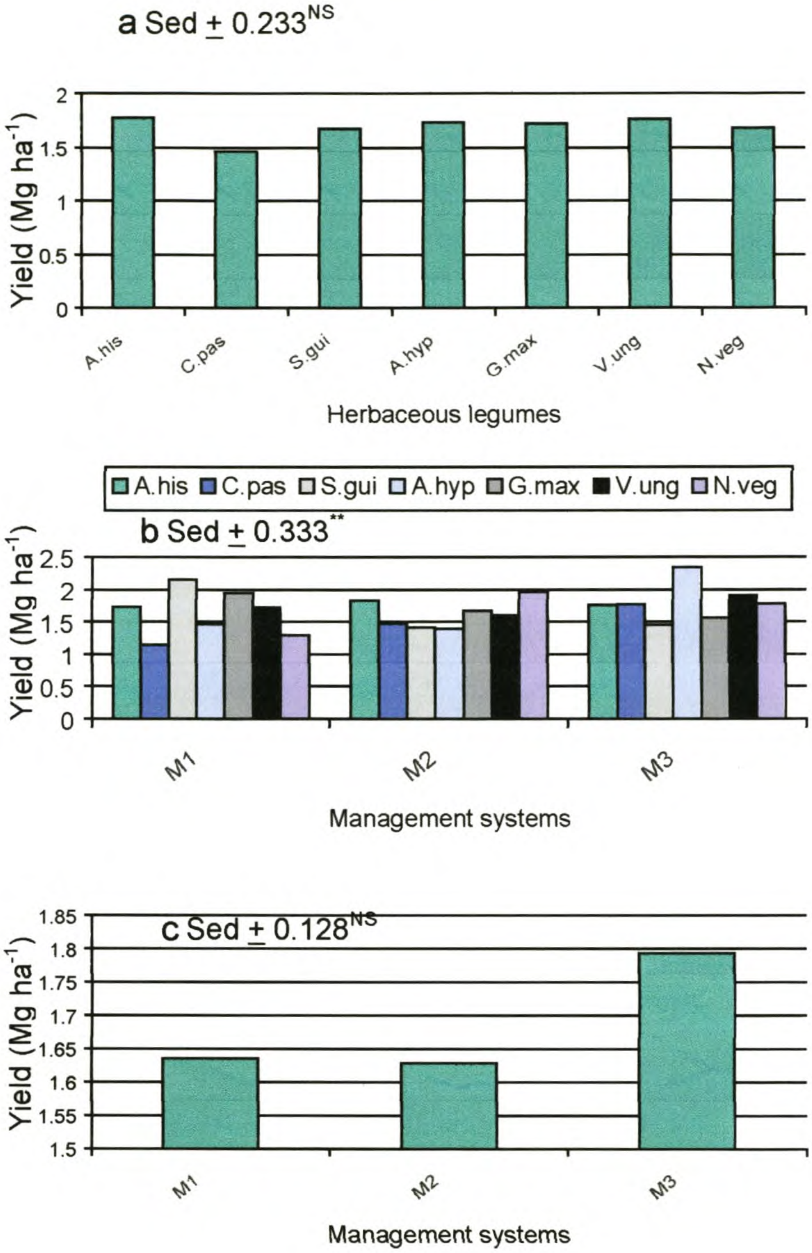


Figure 6.3 The effect of legume species and management systems on weed biomass under maize canopies on a two-year subsequent maize cropping plot, after being fallowed for one year in the northern Guinea savannah, 2002.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.

Abbreviations: *A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.*

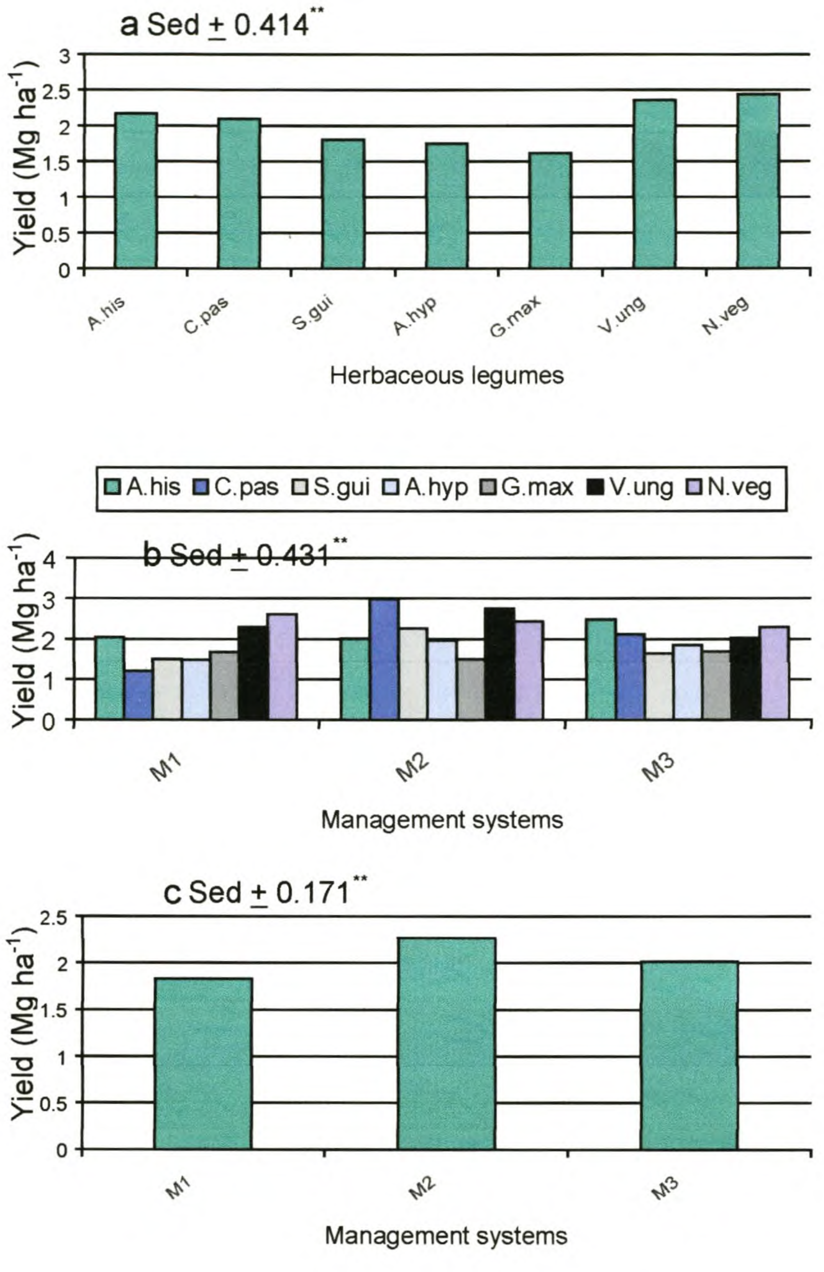


Figure 6.4 The effect of legume species and management systems on weed biomass under maize canopies on a one-year subsequent maize cropping plot, after being fallowed for two years in the northern Guinea savannah, 2002

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation.
M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

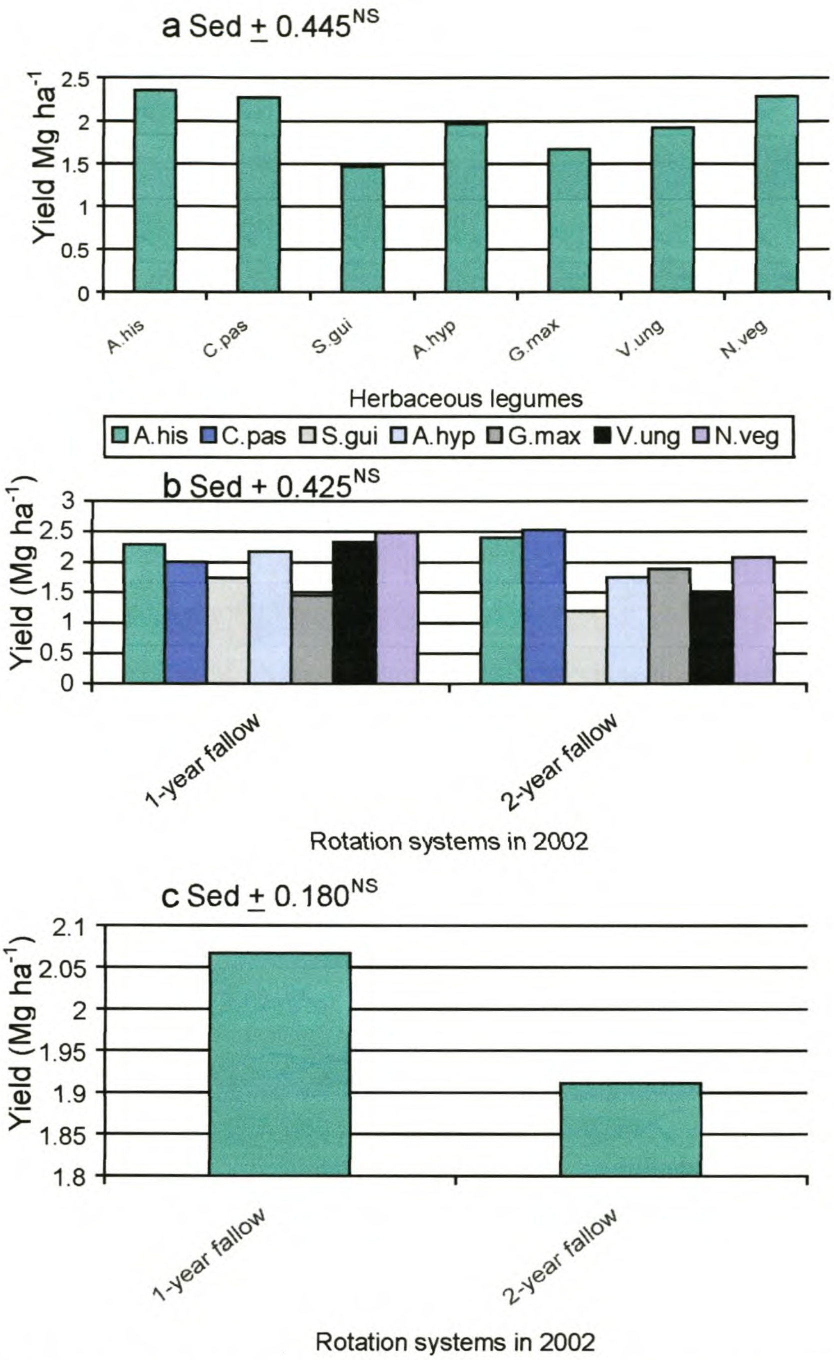


Figure 6.5 The effect of legume species and rotational systems on weed biomass on unweeded micro-plots in maize plots in the northern Guinea savannah in 2002.

a) Effect of legume species, b) Interaction between rotation systems and species, and c) effect of different rotation systems.

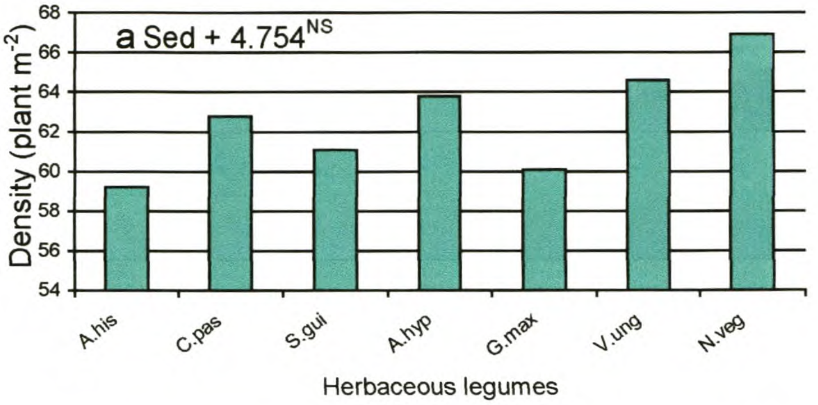
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

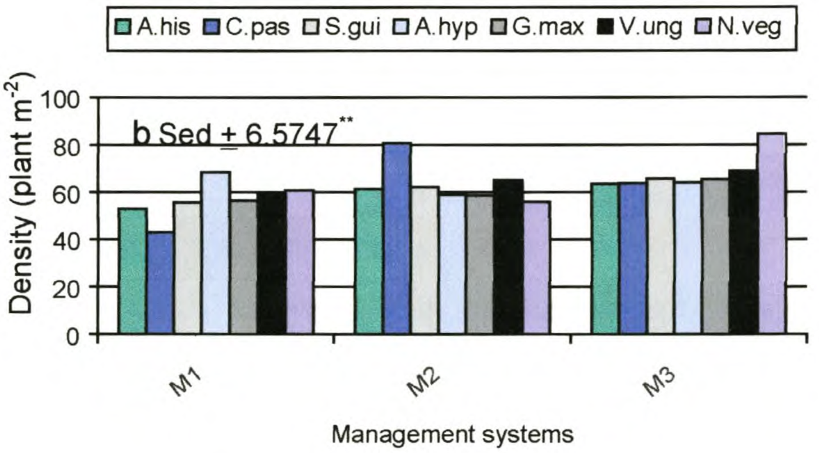
6.3.3 Weed identification and count

Weed count and weed identification were evaluated in maize plots in July 2001, November 2001, and July 2002, respectively. Results on weed density for observed weeds in July and November 2001 did not show significant differences (P>0.05) and for this reason, the data were not shown. However, results of weed density evaluated in July 2002 showed highly significant interactions between legume species and management systems (Fig. 6.6b). The highest weed density under management system *M3* occurred in natural vegetation plots, whereas *C. pascuorum* plots exhibited the highest weed density under management system *M2* and *A. hypogaea* plots under management system *M1*.

About 105 weed species were identified in the northern Guinea savannah (cf. Glossary 1), but only a few of them were consistently present on legume-fallowed plots throughout the experimental period. Frequency of dominant weed species observed in July and November 2001, and July 2002, are presented in Tables 6.2 to 6.4. In June 2001, i.e. about 12 months after field establishment, *Ipomea involucrata* was most prominent on legume plots, while this weed species ranked fourth on the natural vegetation plot (Table 6.2). Other dominant weed species were, for example, *Dactygloctenium aegyptium, Alysicarpus spp, Sida acuta, Sida cordifolia and Seteria palide fusca* (Table 6.2). Results of soil weed seeds in 2001 indicated the presence of new weed species. Prominent among these weeds are *Talinum triangularre, Commelina benghalensis, Spermacoce stachydea, Tridax procumbent, and sedges*

(Table 6.3). Observations on weed species during 2002, i.e. about 24 months after field establishment, showed higher weed density for the legume species tested. Weed composition differed again from the aforementioned species, but sedges were more prominent (Table 6.4). New weed species observed at this stage were *Vernonia galamensis, Leuca martinicensis* and *Fimbrystylis hispidula.* Different weed species associated with each of the legumes were also noted, however, the present analytical method only offered a rudimentary approach to study weed diversity across different environments and sites.





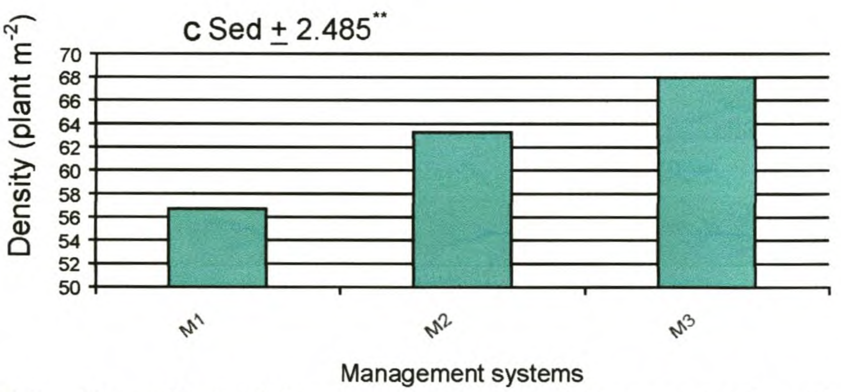


Figure 6.6 The effect of legume species and management systems on weed density in maize plots at 24 months after field establishment (July, 2002) in the northern Guinea savannah.

a) Effect of legume species, b) Interaction between management systems and species, and c) effect of different management systems.
Abbreviations: A.his= A. histrix, C.pas= C. pascuorum, S.gui= S. guianensis, A.hyp= A. hypogaea, G.max= G. max, V.ung = V. unguiculata and N.veg= Natural vegetation. M1=residues left in the field, M2=residues exported out of the field, M3=residues fed to livestock, manure returned.

Table 6.2 Frequency table of dominant weed species in maize plots in the northern Guinea savannah in July 2001.

C. pascuorum	Freq	*V. unguiculata*,	Freq	*A. hypogaea*	Freq	*A. histrix*	Freq	*G. max*	Freq	*S. guianensis*	Freq	Natural vegetation	**Freq**
Ipo inv	11	Ipo inv	10	Ipo inv	14	Ipo inv	14	Ipo inv	11	Sty gui	10	Dac aez	10
Cen pub	11	Sid acu	8	Dac aez	10	Aec his	11	Dac aez	9	Sid acu	10	Set pal	9
Dac aez	10	Set pal	8	Aly spc	9	Sid acu	9	Aly spc	9	Ipo inv	10	Sid acu	7
Sid cor	6	Dac aez	8	Sid cor	8	Set pal	9	Cyn dac	8	Dac aez	9	Cyn dac	7
Sid acu	6	Bar sty	8	Sid acu	7	Dac aez	9	Sid acu	7	Set pal	7	Sid cor	5
Set pal	6	Aly spc	7	Set pal	7	Sen obt	8	Sen obt	6	Aly spc	7	Ipo inv	5
Sen obt	5	Cyn dac	6	Sen obt	7	Aly spc	8	Sed spc	6	Sen obt	6	Bar sty	5
Sed spc	5	Sid cor	5	Sed spc	7	Sid cor	7	Pas orb	5	Cyn dac	6	Aly spc	5
Lin spc	5	Sen obt	5	Cyn dac	6	Lin spc	6	Set pal	4	Sed spc	4	Sen obt	4
Age con	5	Pas orb	5	Sta aug	4	Sed spc	5	Lin spc	4	Phy mir	4	Sed spc	4
Tep ele	4	Eup chr	5	Pen pol	4	Cyn dac	5	Chr spc	4	Lin spc	4	Pas orb	4
Sta aug	4	Sed spc	4	Lin spc	4	Cha spc	5	Cha spc	4	Deg hor	4	Ele ind	4

Nomenclature for weed species is in the glossary
Freq = frequency of weed occurrence m^{-2}

Table 6.3 Frequency table of dominant weed species in maize plots in the northern Guinea savannah in November 2001.

C. pascuorum	Freq.	*V. unguiculata*	Freq.	*A. hypogaea*	Freq.	*A. histrix*	Freq.	*G. max*	Freq.	*S. guianensis*	Freq.	Natural vegetation	**Freq.**
Tal tri	6	Com ben	6	Tri pro	8	Tal tri	6	Com ben	7	Spe sta	6	Spe sta	7
Com ben	6	Spe sta	5	Sed spc	5	Sed spc	5	Tri pro	6	Cel try	6	Pan max	7
Pas foe	5	Pas foe	5	Spe sta	4	Old cor	5	Pas foe	5	Nel can	5	Tal tri	6
Spe sta	4	Tal tri	4	Pas foe	4	Tri pro	4	Spe oxi	4	Tri pro	4	Com ben	6
Old cor	4	Pan max	4	Deg hor	4	Spe sta	4	Sed spc	4	Tal tri	4	Ipo inv	5
Deg hor	4	Nel can	4	Cle vis	4	Spe oxi	4	Deg hor	4	Old cor	4	Old cor	4
Cle vis	4	Cel try	4	Cel try	4	Com ben	4	Age con	4	Gom cel	4	Cel try	4
Pan max	3	Age con	4	Age con	4	Cel try	4	Ipo inv	3	Com ben	4	Tri pro	3
Nel can	3	Ipo inv	3	Spe oxi	3	Pas foe	3	Gom cel	3	Age con	4	Pas foe	3
Ipo inv	3	Eup lie	3	Old cor	3	Pan max	3	Cel try	3	Syn nod	3	Syn nod	2
Eup lie	3	Deg hor	3	Nel can	3	Nel can	3	Tal tri	2	Sed spc	2	Nel can	2
Cel try	3	Tri pro	2	Gom cel	3	Ipo inv	3	Syn nod	2	Pas orb	2	Deg hor	2

Nomenclature for weed species is in the glossary
Freq. = frequency of weed occurrence m^{-2}

Table 6.4 Frequency table of dominant weed species in maize plots in the northern Guinea savannah in July 2002.

C. pascuorum	Freq.	*V. unguiculata*	Freq.	*A. hypogaea*	Freq.	*A. histrix*	Freq.	*G. max*	Freq.	*S. guianensis*	Freq.	Natural vegetation	Freq.
Sed spc	11	Ver gal	12	Sed spc	12	Leu mar	11	Sed spc	12	Sed spc	12	Ver gal	13
Leu mar	11	Leu mar	12	Leu mar	12	Sta aug	10	Leu mar	12	Leu mar	12	Sta aug	13
Dac aez	10	Sed spc	11	Ver gal	10	Sed spc	10	Sta aug	10	Dac aez	11	Leu mar	13
Ver gal	9	Dac aez	11	Sta aug	9	Fim his	10	Ver gal	9	Age con	11	Sed spc	12
Old cor	8	Age con	11	Phy mir	9	Dac aez	10	Old cor	9	Ver gal	10	Bar sty	11
Mit ull	8	Fim his	8	Age con	9	Ver gal	9	Fim his	9	Old cor	9	Fim his	10
Fim his	8	Phy mir	7	Dac aez	8	Old cor	8	Dac aez	8	Fim his	9	Dac aez	10
Deg hor	8	Old cor	7	Cyn dac	8	Age con	8	Age con	8	Sta aug	6	Age con	9
Aca his	8	Ipo inv	7	Leu aby	7	Mit ull	7	Phy mir	7	Leu aby	6	Mit ull	8
Sta aug	7	Deg hor	7	Com ben	6	Deg hor	7	Ver nig	6	Ipo inv	6	Old cor	7
Cen pub	7	Ver nig	6	Old cor	5	Cyn dac	7	Set pal	6	Deg hor	6	Ele ind	7
Age con	7	Sta aug	6	Fim his	5	Phy ang	6	Deg hor	6	Cyn dac	6	Deg hor	7

Nomenclature for weed species is in the glossary
Freq. = frequency of weed occurrence m^{-2}

6.3.4 Weed seed bank

Results of weed seed bank studies in 2000 and 2001 for soils in the northern Guinea savannah in different herbaceous legume plots are presented in Tables 6.5 and 6.6. The size of the weed seed bank at 0cm to 10cm soil depth differs in the two years under study. There was an increase in weed seed bank after one year of field establishment across all treatments (Table 6.5). For instance, in 2000 about 1217 seeds m^{-2} *Oldenlandia corymbosa* was observed, whereas the values increased to 3777 seeds m^{-2} in 2001. The same trend was found for other weed species (Tables 6.5 and 6.6). Sedges, *Oldenlandia corymbosa, Ageratum conysoides and Ludwigia abyssinica,* dominated the seed bank in both years.

Table 6.5 Weed seed bank composition (weed seeds m^{-2}) in plots of different herbaceous legumes in the northern Guinea savannah in 2000.

Observed weed Species	C. pas	V. ung	A. hyp	A. his	G. max	S. gui	N. veg	Total seeds
	Seeds m^{-2}							
Ageratum conysoides	131	80	206	246	177	126	131	**1097**
Alysicarpus spp						11		**11**
Amaranthus spinosus	11	6	40				6	**63**
Amaranthus viridis			11					**11**
Aspilia africana	6		6					**11**
Borreria stachydea				6		17		**23**
Boerhavia diffusa							6	**6**
Brachiaria jubata					6			**6**
Broad leaves	17		11		6	17		**51**
Cynodon dactylon		6	6	6	11	23	6	**57**
Dactygloctenium aegyptium						11		**11**
Degitaria horozontalis	6							**6**
Desmodium tortuosum		6						**6**
Grasses species	51	91	137	120	40	229	234	**903**
Hibiscus			11					**11**
Ipomea involucrata	6							**6**
Ipomea eriocarpa					11			**11**
Ludwigia abyssinica	34	91	74	126	69	63	63	**520**
Leuca martinicensis	34	126	51	46	29	17	63	**366**
Luffa aegypti			11			6		**17**
Oldenlandia corymbosa	257	91	131	206	206	126	200	**1217**
Sedges	114	303	291	377	434	194	543	**2257**
Seteria barbata			6					**6**
Sida acuta		6	6					**11**
Solanum nigrum							6	**6**
Spermacoce stachydea	6							**6**
Starchytapheta augustifolia				6				**6**
Tephrosia elegan		6	6				6	**17**
Tridax procumben	6			6			6	**17**
Vernonia galamensis			34					**34**
	680	**811**	**1040**	**1143**	**989**	**840**	**1269**	

C.pas = Centrosema pascuorum ILRI 9857; V.ung = Vigna unguiculata IT89KD-288; A.hyp = Arachis hypogaea UGA 5; A.his = Aeschynomene histrix ILRI 12463; N.pas = natural pasture; G.max = Glycine max TGX 1448-2E; S.gui = Stylosanthes guianensis ILRI 15557.

Table 6.6 Weed seed bank composition (weed seeds m^{-2}) in plots of different herbaceous legumes in the northern Guinea savannah in 2001.

Observed weed species	C. pas	V. ung	A. hyp	A. his	G. max	S. gui	N. veg	Total seeds
	◄			Seeds m^{-2}			►	
Ageratum conysoide	406	326	400	406	440	280	463	**2720**
Amaranthus spinosus	46		103			6		**154**
Borreria stachydea					11			**11**
Boerhavia diffusa	29						17	**46**
Broad leaves		177	74	109	131	126	166	**783**
Celosia trigyna						6		**6**
Chromoleana odorata	6							**6**
Cynodon dactylon	23	17	74		6	34	17	**171**
Eleusine indica						6		**6**
Eragrotis turgida						6		**6**
Euphorbia hirta						6		**6**
Euphorbia hyssopifolia				6				**6**
Grasses species	91	103	97	46	23	74	109	**543**
Ipomea involucrata		6						**6**
Ipomea eriocarpa	11				6			**17**
Ludwigia abyssinica	91	63	131	11	23	34	114	**469**
Leuca martinicensis			51		34	23	109	**217**
Oldenlandia corymbosa	709	377	400	457	240	931	663	**3777**
Penisetum polystachion		6						**6**
Schwvenkia americana	6							**6**
Sedges	834	909	629	537	474	766	514	**4663**
Seteria palide fusca					46			**46**
Solanum nigrum						6		**6**
Axonipus				6				**6**
Spermacoce stachydea	6			6		6		**17**
Starchytapheta augustifolia		6	17	11	29	6	6	**74**
Tephrosia elegan	6	11	6			6		**29**
Vernonia galamensis			11				6	**17**
	2263	**2000**	**1994**	**1594**	**1463**	**2320**	**2183**	

C.pas = Centrosema pascuorum ILRI 9857; V.ung = Vigna unguiculata IT89KD-288; A.hyp = Arachis hypogaea UGA 5; A.his = Aeschynomene histrix ILRI 12463; N.pas = natural pasture; G.max = Glycine max TGX 1448-2E; S.gui = Stylosanthes guianensis ILRI 15557.

6.4 *Discussion*

6.4.1 Weed dry matter yield (biomass) across the experimental plots

Monthly weed biomass under the selected herbaceous legumes in the northern Guinea savannah generally declined as the length of the cropping season increased, while that for the natural vegetation increased until after the second month of planting. These results were in accordance with Derksen *et al.* (1995) and Kamara *et al.* (1999), who observed higher total weed biomass in continuous cropping treatments compared to legume fallow treatments. This is probably due to a smothering effect of the legumes on the weed population.

The higher weed biomass observed in 2002 in the maize plots in the *2yrL1yrM* rotation system could result from the enhanced soil fertility level as shown in chapter 5 section 5.3.1, because residual effects of planted legumes on follow-up crops, and therefore also on weeds, are well known (Gichuru, 1991). It is necessary to mention that weed populations, especially in the 2001 and 2002 cropping season, under maize canopies fluctuated and were dependent on environment and may have been influenced by the relative timing of the management systems. In 2001, however, *M3* had lesser weeds than the other management systems, but in contrast, in 2002 there were more weeds on these plots than in the other management systems (Figs. 6.2 and 6.3). In 2001, the maize plot following *A. histrix* had fewer weeds than other legumes, but this varied much more in 2002, when maize plots after *A. hypogaea* tended to have highest weed populations, especially on plots that received manure. These observations were in accordance with the conclusions of Derksen *et al.* (1995), who opined that weed assessments in long-term studies may produce results that are not representative of community response to production practices. Therefore, a change in relative composition had occurred, rather than a consistent change in weed associations. The non-uniformity of weeds in a field also complicates matters. Plots of a few meters apart in a field may have different weed communities and that may make differences between treatments hard to determine (Hurle, 1998).

6.4.2 Weed identification and count

Differences in weed suppression observed under different legumes were not significant in 2001 and 2002 following legume fallow, though weed density was significantly influenced by management systems in 2002 (Fig. 6.6). In comparison with the natural vegetation, results indicate higher weed density especially on plots that had manure returned. This observation may be partly due to improvement of nutrient cycling that favours germination of weed seeds. All the legumes except *C. pascuorum* had higher weed density than natural vegetation for management system *M2*.

The distribution of groups of weed species in the study appeared to be driven by the treatment combinations. For instance, dominant weed species differ across different legumes and natural vegetation. According to Weber, Elemo and Lagoke (1995), the majority of weed species composition on legume plots resulted from the effects of treatment, e.g. *Ipomea involucrata,* which was prominent on legume plots, ranked fifth on the natural vegetation plot (Table 6.2). Although species composition changed on both legume plots and natural vegetation plots at 12 months, distinct differences in weed species composition on legume and natural vegetation plots remained afterwards. As indicated, the changes in species composition could be due to enhanced soil fertility, competition or just normal succession in the case of natural vegetation. In the context of this study therefore, the contribution of legumes to soil fertility over time could be responsible for the observed varying weed compositions. That does not, however, explain the species composition change in natural vegetation.

6.4.3 Weed seed bank

The herbaceous legumes planted significantly affected the size of the seed bank. There was a general increase of the weed seed bank after one year of fallow with either legume or natural vegetation. However, the increase in the seed bank under natural vegetation was much higher than under legumes. The low seed numbers in the first year could be explained by the fact that the soil was fallowed for about four to five years under natural vegetation before the experiment commenced. The extended natural vegetation would have depleted the seed bank of arable weeds, which thrive under conditions of soil disturbance. The first year of legume fallow, where the soil was disturbed, could have caused the increase in weed numbers and, therefore, an increase in weed seeds. Similarly, a significantly ($P<0.05$) positive correlation 0.234 (R^2 = 0.03^{**}) was observed between weed composition and soil weed seeds in the northern Guinea savannah within the same period. It is worth mentioning that weed seed composition changes are probably due to smothering effects by herbaceous legumes, which gives room for new weed species. Increased weed seed densities per meter square observed after one year of fallow with these legumes may be attributed to the legumes' good canopy cover, high biomass, and litter production, especially on *C. pascuorum* and *S. guianensis* plots. This could result in unfavourable conditions for germination of the weed seeds, hence the increase in the seed bank, because there was no loss due to germination. These results are in accordance with the experiment conducted by Hill *et al.* (1989), who found an increase in the weed seed bank after one cycle of the rotation.

6.5 Conclusions

This study showed that the suppression of the undergrowth weeds were possible under appropriate management systems. Selected herbaceous legumes were superior to natural vegetation in relation to weed population dynamics in the systems (Fig. 6.1). However, this is more pronounced under forage legumes, than under grain legumes. Higher weed biomass in plots applied with manure may be an indicator of enhanced soil nutrient content. Reports on weed seed bank densities confirm the influence of management systems on weed flora. On this note, therefore, the intensification of cropping systems such as rotations with legumes could drive weed biomass and weed seed bank to higher densities. Inclusion of herbaceous legumes could keep weed pressure at low levels and also improve the nutrient status of the soil. It appears, however, as if the legume fallow should be at least two years to be really effective in reducing weed seed banks and weed biomass.

6.6 References cited

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Chapter 7

The role of livestock in a sustainable crop-livestock production systems

7.1 Introduction

Livestock, and particularly small ruminants, traditionally graze on natural vegetation, forest areas, roadsides, fallow lands, crop re-growth, crop residues such as straw and oilseeds, and other by-products. Owing to limited grazing opportunities, especially during the dry season, livestock are stall-fed with forage-based diets and small quantities of purchased concentrate feeds (Lekasi *et al.*, 2002). When abundant feed is available, livestock can be considered a form of wealth, power and security (Schiere, Abraham & van Keulen, 2002). To improve livestock production, sustainable solutions to seasonal deficiencies in feed availability and quality are required. Although natural vegetation provides the cheapest source of nutrients for ruminants, the low quantity and poor quality of available feed from this source seriously affects livestock production, particularly during the dry season (Irene, 2002).

The intensification of agricultural systems in SSA has resulted in declining nutrient availability, soil acidification, soil compaction and build-up of pest problems seriously affecting the soil productivity (Weber, 1996). The sustainability of livestock production systems depends to a large extent on how they are integrated with crop production systems. The livestock can provide input to cropping systems in term of manure and draft power, while the crops can provide feed for livestock.

Studies on the use of manure for crop production are well documented (Jabbar, 1992; Muhr, 1998; Larbi *et al.*, 2002) and many crop trials have looked at rates and methods of manure application, effects on soil chemical properties and on soil moisture dynamics (Lekasi *et al.*, 2002).

The objectives of this study, therefore, were to investigate the relationships in a broader perspective, *viz*. livestock performance, crop production and weed dynamics in the systems. This was undertaken using a holistic approach to assess effects of composted feed residues on maize productivity and finding a link between the digestibility of selected legumes on intake and growth of small ruminants. Detailed reports on part of these objectives were documented in chapters 5 and 6, while the present chapter focuses on the reciprocal benefits of feeding herbaceous legumes to small ruminants.

7.2 Materials and Methods

7.2.1 Feeding of experimental rams

The experimental rams were fed according to their dietary-based treatment groups. Water was supplied *ad libium*. 200 grams of concentrate supplements, comprised of 75.2% maize offal, 23.8% cotton seed cake, 0.5% bone meal and 0.5% common salt, compounded to contain 27% crude protein, was given at 0700, shortly before the daily feed ration. The daily feed ration consisted of 50% of selected herbaceous legumes used in this study and natural vegetation, and

50% maize stover. Half of the daily feed ration was given at 0800 and the remaining half at 1200 hrs.

7.2.2 Procurement of rams and welfare

Twenty eight Yankasa rams, average age 18 months, mean initial liveweight 21.1kg, s.e. 5.6, were used for a detailed feeding trial in the northern Guinea savannah (cf. chapter 3, section 3.1.1) at the National Animal Production Research Institute (NAPRI), Amadu Bello University (ABU), Zaria, Nigeria (Longitude 8^0 19'N, Latitude 12^0 12'E) over a 56-day period. The 28 rams were randomly allocated to each of the seven treatment groups. At the beginning of the experiment and fortnightly thereafter, the rams were dipped, using Acaricide insecticide solution. Routine de-worming with Benzal Drench® and Peste des Petits Ruminants (PPR) TCRV® vaccine was administered at the start of the experiment. The rams were individually housed in stalls in a barn roofed with aluminium sheets. Each stall measured 4m X 2m. Each stall had a drinking bowl and a feeder located in front. The cleaning of the stalls was done daily. The welfare of the rams used for the experiment was paramount throughout the period and appropriate animal welfare procedures were adhered to.

7.2.3 Sampling the feeding materials

The herbaceous legumes and natural vegetation fed to rams were hand-cut at maturity and allowed to dry naturally. Feed consisted of herbaceous legumes and natural vegetation, while maize was added as a basal diet. Prior to the start of the feeding experiment, the feed was chopped into pieces approximately 2cm to 5cm long with a tractor-driven chopper. Rams were fed half of their daily feed ration at 0800 and the remaining half at 1200. Refused feeds were collected and weighed each morning at 0700. Shortly after this measurement, leftover feeds were mixed (trampled) with voided faeces and urine. The compost, composed of refused feeds, faeces, urine and spill over water, was occasionally heaped in a corner in the pen to simulate farmers' practices. Faeces and urine were collected individually in metabolic crates from penned rams fed with each treatment in the middle of the experimental period. The crates were fitted with excreta separators, which directed faeces and urine into different containers positioned at the base of the instrument. Sub-samples of feeds, faeces, urine and compost were collected for chemical analysis.

These samples were dried in the oven at 105°C for 24 hours for dry matter determination. Another sub-sample was dried at 65°C for 48 hours for chemical analysis. Procedures for chemical analysis have discussed (cf. chapter 4, section 4.2.2). The chemical analyses were carried out for total nitrogen, phosphorus, organic matter, NDF, ADF, HEM, Lignin and cellulose, as described in chapter 4, section 4.2.2. Nitrogen values were multiplied by 6.23 to obtain crude protein values.

7.2.4 Data analysis

Statistical comparison of differences in liveweight, feeds, faeces and total compost were performed using Proc GLM methods of SAS (SAS 1998). Differences in treatment means were compared using standard error at a 5%

significance level. The model used in the statistical analysis is given in appendix 13.

Polynomial regression was used as a tool to assess the reciprocal benefit of feeding herbaceous legumes and natural vegetation (Fig. 7.1) to rams and the model is given as:

Weight gain $Y = f\ (X_{t+1})$,

where Y is daily weight gain in gram, X = feed residues and t = time

7.3 Results

7.3.1 Chemical analyses

Crude protein in the feed residues ranged from 170g kg^{-1} DM for *A. hypogaea* to 62.4g kg^{-1} DM for *A. histrix* (Table 7.1). Concerning dry matter digestibility, *S. guianensis, G. max* and *A. histrix* were rated high, while *A. hypogaea* (177.6g kg^{-1} DM) had the least digestible material.

With the exception of *A. hypogaea*, the NDF concentration of all herbaceous legumes was above 400g kg^{-1} DM. Generally, cell wall constituents, such as NDF, ADF and Lignin, were lowest in *A. hypogaea* and highest in *G. max* (Table 7.1). Non-degradable hemicellulose contents had a similar trend.

Results on chemical analyses for urine, faeces and compost are shown in Table 7.2. Nitrogen concentration in the urine ranges between 12.2g kg^{-1} DM in *A.*

hypogaea to 33.4g kg^{-1} DM in *G. max*. This trend was maintained in faeces nitrogen. Nitrogen concentrations in compost were highest for *A. hypogaea* and least for *G. max*. Generally, phosphorus concentrations were higher in urine than in faeces (Table 7.2). It is worthwhile to note that rams fed with *A. histrix* had higher phosphorus levels in their urine compared to other treatments, while the lowest urine nitrogen levels were found in those rams fed with *C. pascuorum*. However, none of these differences were significant (P>0.05).

The organic matter concentration in compost differed significantly. About 162g kg^{-1} DM of organic matter was realised on composted materials for *A. hypogaea,* whereas the values decreased across other treatments. The lowest amount of organic matter was observed from *S. guianensis,* which was 95.1g kg^{-1} DM.

7.3.2 Weight gain of rams

Table 7.3 shows weight gained by rams fed with selected herbaceous legumes in 2002. Rams fed with herbaceous legume-based diets gained more weight than those fed with natural vegetation. Rams fed with *A. hypogaea* gained 85.7g day^{-1} weight, followed by those fed with *S. guianensis,* while the lowest weight increases were seen in rams fed with natural vegetation.

Table 7.1 Chemical composition of selected herbaceous legumes used for detailed feeding trail during the dry season in 2002 expressed in g kg^{-1} dry matter.

Feed sources	CP	P	OM	DMD	NDF	ADF	HEM	LIG	CC
					g kg^{-1} DM				
C. pascuorum	85.2	1.2	905.5	330.1	667.5	514.7	152.8	128.7	386.1
V. unguiculata	101.4	1.4	922.4	348.3	633.3	548.1	85.2	125.6	422.4
A. hypogaea	170.3	1.7	764.3	177.6	354.8	272.5	82.3	81.8	190.7
A. histrix	62.4	1.0	908.6	372.0	707.6	596.6	111.0	136.5	460.1
Natural vegetation	78.5	1.6	884.8	359.9	697.8	513.5	184.4	102.0	411.4
G. max	74.6	1.1	953.9	380.4	728.8	639.7	89.2	155.2	484.5
S. guianensis	88.9	1.0	938.5	370.2	692.9	593.3	99.6	135.9	457.4
Maize stover	61.8	1.4	845.0	356.3	695.8	486.8	209.0	92.0	394.8
Sed $\pm$	13.1*	0.2*	24.5*	16.8*	31.7*	24.3*	19.2*	6.4*	22.8*

DMD = 0.98 CC + NDF (1.473 – 0.789 log ADF) – 12.9,
Where CC is cell contents, NDF the neutral detergent fibre and ADF the acid detergent fibre.
Others are: DMD = Dry matter digestibility, CP= Crude protein, P = Phosphorus, OM = Organic matter, HEM = Hemicellulose.
** = signifncat at P = 0.05.*

Table 7.2 Chemical composition of urine, faeces and compost[1] in 2002.

Feed sources	Urine		Faeces		Compost		
	N	P	N	P	N	P	OM
	g kg^{-1} DM						
C. pascuorum	16.7	48.9	28.9	9.9	20.00	4.4	109.6
V. unguiculata	20.9	111.9	31.3	8.2	18.5	2.8	95.1
A. hypogaea	12.2	79.1	32.1	7.5	21.8	4.1	162.0
A. histrix	21.3	203.4	31.1	10.0	18.8	4.2	113.5
Natural vegetation	17.5	84.1	29.6	10.0	17.3	4.3	120.2
G. max	33.4	70.2	36.1	12.2	15.2	2.9	100.3
S. guianensis	25.8	105.3	28.6	8.1	15.7	3.0	85.6
Sed $\pm$	8.489 ^{NS}	35.007 ^{NS}	2.258 ^{NS}	1.028 ^{NS}	1.771 ^{NS}	0.499 ^{NS}	15.03*

[1]*Compost in the context of this study refers to the refused feeds that were deliberately allowed to be mixed with faeces and urine. The objective was to capture as much urine nitrogen as possible.*
NS = not significant at P = 0.05
** = significant at P = 0.05.*

Polynomial regression was used as a tool to assess the reciprocal benefit of feeding herbaceous legumes and natural vegetation to rams. This technique was used to visualise intrinsic features using quadratic fit within the period of the feeding trial (Fig. 7.1). There was no clear pattern between forage and grain legumes fed to livestock. However, the graph showed a sharp increase in weight in rams fed with *A. histrix*, *S. guianensis* and *G. max*. The patterns observed for *C. pascuorum*, *A. hypogaea* and *V. unguiculata* tended to improve initially and then drop progressively thereafter. In contrast to this, an immediate declining trend was observed for natural vegetation. It has to be emphasised that this was a rudimentary approach to discern the main ways in which legume species and natural vegetation could contribute to liveweight gain when fed to rams. It is important to stress that this approach has yet to be validated, it only forms part of the author's multi-faceted approach to arrive at a constructive conclusion for this complex project.

Table 7.3 Effect of selected herbaceous legumes based diets on weight gains, refused feeds and faeces voided by rams at the end of the feeding experiment in 2002.

Parameters considered	Roughage source							Sed±
	A.his	C.pas	S.gui	V.ung	G.max	A.hyp	N.pas	
No. of animals required	4	4	4	2	4	4	4	NA
No. of feeding days	28	49	49	42	49	35	49	NA
Total No. of animals days	112	196	196	84	196	140	196	NA
Mean initial weight (kg)	23.8	18.6	16.3	18.7	15.4	16.4	13.7	1.547**
Mean final weight (kg)	24.7	21.8	20.4	20.7	18.5	19.4	16.8	1.456**
Total weight gain (kg)	0.9	3.2	4.1	2.0	3.1	3.0	3.1	NA
Daily gain (g)	32.0	65.3	83.7	47.6	63.3	85.7	63.3	NA
Mean refused feeds (kg)	23.0	17.6	23.0	26.4	31.6	22.4	18.8	3.439^{NS}
Mean voided faeces (kg)	47.9	36.3	25.2	42.2	46.2	63.8	27.3	9.03^{NS}
Compost (kg)	70.8	53.9	48.1	68.2	77.7	86.1	46.2	11.457^{NS}
Compost/sheep/day (g)	633.0	275.0	245.9	816.7	396.9	615.7	286.2	NA
Compost kg/ha	210.0	91.7	81.8	270.6	132.1	205.0	78.6	NA

NA = Not applicable

A.his =Aeschynomene histrix; C.pas = Centrosema pascuorum, S.gui = Stylosanthes guianensis, V.ung = Vigna unguiculata G.max = A.hyp =Arachis hypogaea and N.pas = Natural vegetation

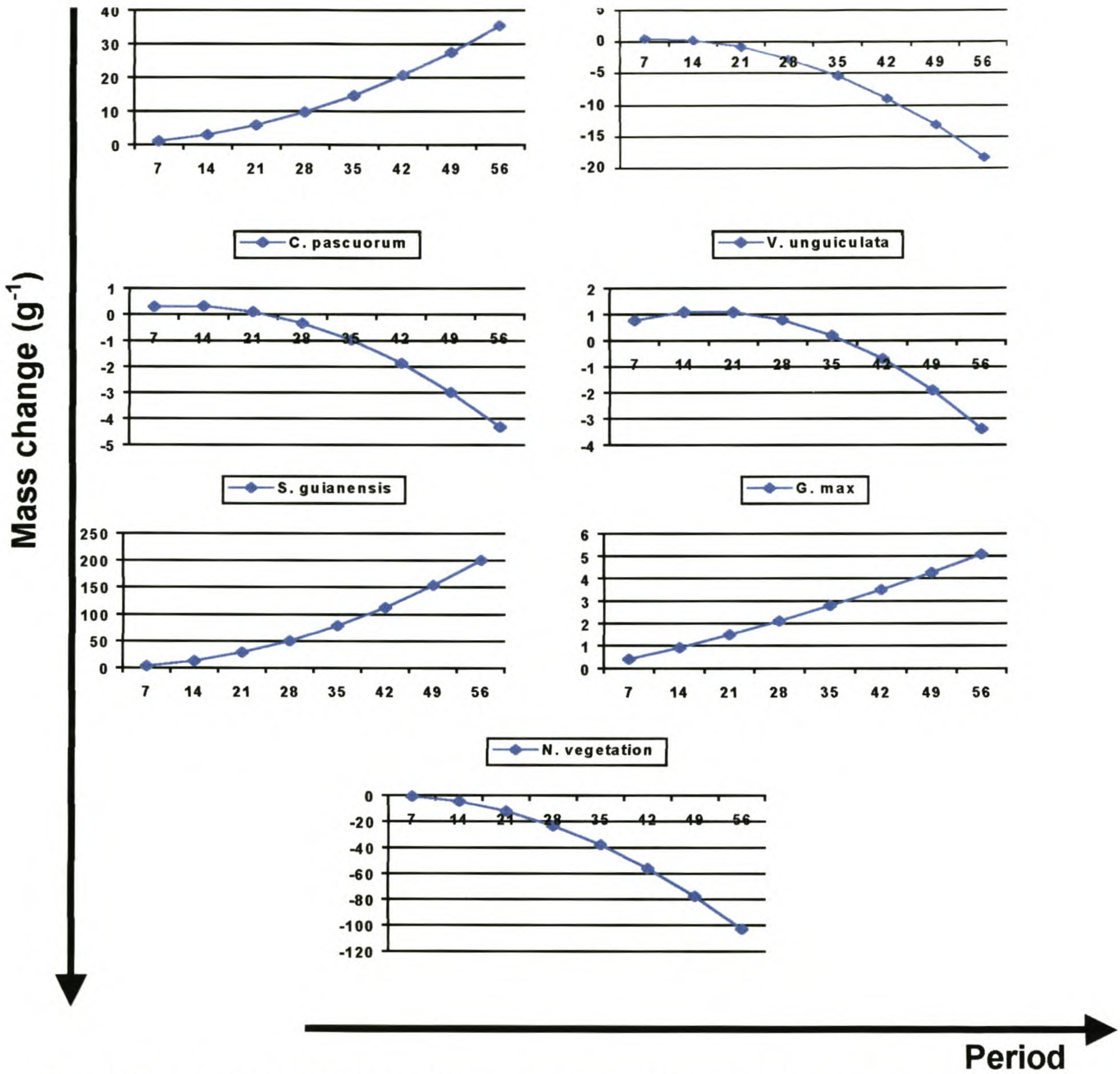

Figure 7.1: Schematic presentation of polynomial regression showing patterns for herbaceous legumes and natural vegetation fed to rams for 56 days in the northern Guinea savannah.

Polynomial equations is given as:

A. histrix	***$61.634t + 10.204t^2 - 28.571$***	***$(R^2 = 0.9764)^{**}$***
A. hypogaea	***$132.65t - 8.1633t^2 - 75.509$***	***$(R^2 = 0.9155)^{**}$***
C. pascuorum	***$50.766t - 2.296t^2 + 37.754$***	***$(R^2 = 0.8481)^{0.10}$***
V. unguiculata	***$107.96t - 3.0614t^2 + 160$***	***$(R^2 = 0.9093)^{0.10}$***
S. guianensis	***$3.5715t^2 - 14.796t + 69.389$***	***$(R^2 = 0.9648)^{**}$***
G. max	***$63.776t + 0.5103t^2 - 74.49$***	***$(R^2 = 0.9783)^{**}$***
N. vegetation	***$164.29t - 35.715t^2 - 71.43$***	***$(R^2 = 1.0)^{**}$***

** = significance at P = 0.05.

7.4 Discussion

7.4.1 Chemical analysis

Results from feeding legumes in this project are promising. The basal diet and the range of quality in the six diet supplements, *A. histrix, C. pascuorum, S. guianensis, A. hypogaea, G. max and V. unguiculata*, provided varying amounts of feed biomass and concentrations of nitrogen and phosphorus and fibre fraction contents during the experimental period. Results of chemical analyses were consistent with other reported analyses of tropical forage legumes (Larbi *et al.*, 1998; Fondevila, Nogueira-Filho & Barrios-Urdaneta, 2002). However, there were variations among the legumes, with consistently lower values of organic matter, NDF, ADF hemicellulose, lignin and cellulose for *A. hypogaea,* whereas higher values of these parameters were found for *G. max*.

The proportion of nitrogen voided in faeces and urine and the susceptibility of nitrogen to losses in the environment depends on the animal's diet (Powell & Williams, 1993). In this study therefore, faecal nitrogen content was relatively high compared to the urine nitrogen content (Table 7.5). In contrast, levels of phosphorus in urine are relatively higher than in faeces. This contradicts the findings of CAB (1984) and Ternouth (1989), that most phosphorus is voided in faeces. The present result is, however, in agreement with the findings of Powell *et al.* (1998). Similarly, Delve *et al.* (2001) observed a small amount of nitrogen excreted in the urine - less than 1% of the total excreted nitrogen. Animals that have diets of lower digestibility excrete relatively high amounts of nitrogen in the form of manure. Relatively high levels of fecal nitrogen were observed for *G. max*, *A. hypogaea, A. histrix* and *V. unguiculata*, though not significantly different from natural vegetation. This gives an indication that these legumes could be a better source of nitrogen from manure for subsequent cropping. Nitrogen from urine can be readily volatilised and leached from the soil, whereas fecal nitrogen decomposes slowly in soil, and is therefore more available for recycling by plants.

7.4.2 Weight gain

Overall results indicate that rams fed with *A. hypogaea* had the best daily weight gain, compared to other legumes and natural vegetation (Table. 7.6). This could be due to the high crude protein content in the forage (Table 7.4). It is worthwhile to note that the level of OM and nitrogen intake was not actually measured in this study. However, the amount of refused feeds from the resultant 3% body weight feeds fed to small ruminants could pose a better understanding of the OM and nitrogen intake. Ironically, refused feeds, as observed in this study, varied across the main treatments. While lower amounts of feeds were left after feeding with *C. pascuorum, A. hypogaea, A. histrix* and *S. guianensis,* the leftover levels were always high for *V. unguiculata*, *G. max* and natural vegetation. This intake differences observed could probably be attributed to the fibrous stems in *V. unguiculata*, *G. max* and natural vegetation, coupled with levels of their acceptability by small ruminants and digestibility in the rumen proposed by Delve *et al.,* (2001). The dependence of faeces and urine amounts on dry matter intake has been reported in a study conducted by Kirchgessner &

Kreuzer (1986), who observed that slurry production and dry matter content increased with dry matter intake, suggesting a linear relationship between the daily feed intake and the amount of faeces and urine excreted.

Results showed that feeding legumes and natural vegetation to rams under zero grazing conditions can increase liveweight. Higher daily weight gain observed from legumes than natural vegetation could be attributed to the quality difference in the feed material. This is in agreement with the findings of Adamu (1998), who reported on the use of legumes in the northern Guinea savannah as supplements to cereal-based diets. Feeding with legumes produces positive weight gain more often than not, compared to feeding with natural vegetation.

7.4.3 Prediction using regression equation and weight gain

Polynomial regression was used as a rudimentary method to illustrate trends in weight change, which was contradictory to the actual results in Table 7.6. The regression showed that feeding rams with *A. histrix, S. guianensis* and *G. max* provided better results over a 56-day period, compared to *C. pascuorum, A. hypogaea, V. unguiculata* and natural vegetation. This indicates that the beneficial effect of supplementing livestock feeds with leguminous by-products is greater than that given by the natural vegetation, according to Dicko *et al.* (1983). Daily weight gain of rams fed with natural vegetation tended to decrease as the feeding period progressed, while rams only lost weight in the *C. pascuorum, A. hypogaea* and *V. unguiculata* treatments after an initial growth stage.

7.5 Conclusions

As we have seen in this study, livestock gained appreciable weight when fed with legumes, compared to when they were fed natural vegetation. This study has demonstrated a full integration of crop and livestock production systems, which provides a source of manure for the fields, and also supplies forage to feed livestock, especially during the dry season.

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Chapter 8

Integrated crop-livestock-weed-soil simulation models

8.1 Introduction

The potential to increase crop-livestock production in mixed crop-livestock farming systems in SSA is limited, due to low and erratic rainfall, poor soil fertility, weed competition, lack of feed supplements and very limited availability of external nutrient sources in the form of inorganic fertiliser (Powell, Ikpe & Zomda, 1999). The cycling of high quality plant biomass through livestock into faeces and urine enhances both livestock and crop production. Powell, Fernandez-Rivera and Hofs, (1994) found that nutrient cycling could be enhanced by developing diets that satisfy the nutritional demands of livestock, while producing excreta less susceptible to losses when applied to cropland. For this system to remain viable, most plant biomass must be fed to livestock, with faeces and urine used as soil fertility amendments (Powell *et al.*, 1999; Thornton & Herrero, 2001).

In terms of the study of crop-livestock systems and their interactions, modelling offers the only realistic way of identifying and quantifying the subtle, but often highly significant, interactions that occur between the different components of the farming system. There must be trade-offs and balances and a better understanding of the interplay between various components, which can help us to make recommendations about how to get the best from the system.

The systems investigated in this study provide opportunities to improve natural resource management (NRM) through integrated crop-livestock systems. For example, animal manure contributions to soil fertility is an important attribute, in view of increasing shortages of inorganic fertilisers, while herbaceous legumes and crop residues (stover) constitutes an important source of livestock feed in crop-livestock systems (Tarawali, Peters & Schulze-Kraft, 1999; Larbi *et al.,* 2002). Although smallholder farmers adopt different management systems, which are considered a major issue affecting the sustainability of crop-livestock systems in the tropics, information is inadequate as to the holistic interaction of all factors involved in the production systems.

In this context, the present study takes a holistic approach to crop-livestock interactions involving weeds, soil fertility and herbaceous legumes. Attempts are made to proffer models suitable for the three management systems and to investigate the contributions of individual components in the system.

8.2 Crop-livestock, weeds, soil fertility component interactions

Within the framework of Fig. 8.1, and in the case of the different management systems proposed for this study, (cf. Chapter 1, Fig. 1.1), several interactions exist between various components in the system. For instance, the interactions between organic resources and livestock revolve mostly around the supply of nutrients and energy in feed, hence it is imperative to use models capable of predicting animal performance from given plant and animal characteristics. In the present study, the nutritional inputs were managed directly, with feeds offered to stall-fed small ruminants. Stall-feeding is common in mixed farming systems, because it allows farmers to exert more control over the valuable manure output of their animals and also reduces the possibility of damage to crops that may be caused by free-ranging livestock. It is often seen as a 'more advanced' crop-livestock intensification step (Adamu, 1998).

The livestock-soil (land) interaction includes the production of manure and compost. In smallholder farming systems, livestock play a key role in the cycling of nutrients to crops, wherever the crops and livestock are associated (Powel *et al.*, 1994). Similarly, mulching materials and forage residues are products of interactions between weeds and soil (Fig. 8.1).

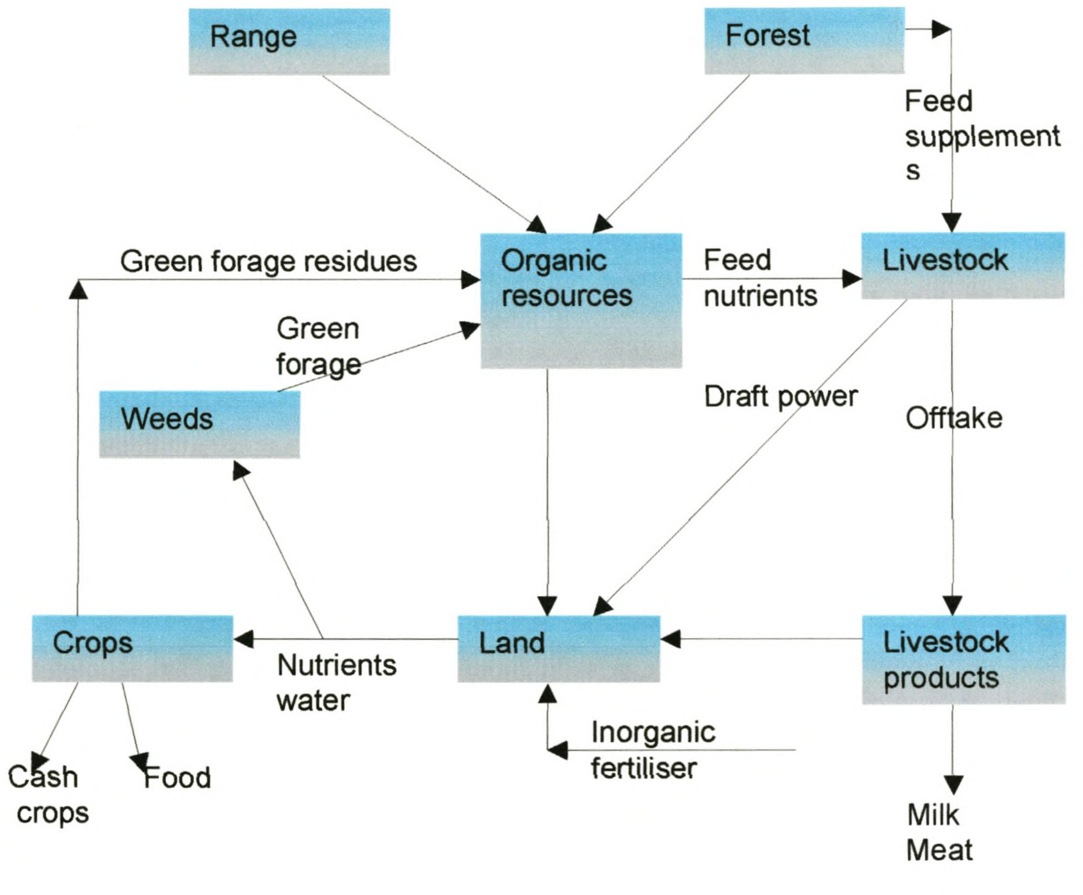

Figure 8.1 Schematic representation of a farming system based on the integration of crop-livestock systems.
Source: Thornton & Herrero, (2001).

It is also clear that there is a range of models that have dealt successfully with livestock production utilisation and related purposes (Appendix 4). However, there has not been a single unifying framework that has dealt satisfactorily with all the components considered in this study. The interactions between crops, livestock, weeds and soil fertility under different legume species and management systems require a range of models, varying in level of aggregation, to explain the data collected.

8.3 Modelling processes in the system

Expressing the complexity involved in this study poses an enormous difficulty for modelling. Modelling in context is a way of integrating information in a rational way, and as such, can include a variety of methodologies. LIMDEP (Greene, 1998) and Maple V (Maple, 1998) are integrated software programs for the estimation of regression models and non-linear models for limited dependent variables. This technique relates the management systems to applicable factors, since we cannot model all the processes simultaneously.

The general model is given as:

Crop = Y_1 in kg and Livestock = Y_2 in kg.

Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3 in kg;

Herbaceous legumes = x_4 in kg; Maize stovers = x_5 in kg,

where Y_1 and Y_2 are dependent variables and

x_1, x_2, x_3, x_4 and x_5 are independent variables.

x_1, x_3, x_4 and x_5 can be expressed in terms of yield or any other component, while x_2 can be expressed in terms of the soil nutrient composition. For example, soil nitrogen values could be used for x_2, while maize grain could be used for Y_1 in the present study.

Therefore, since

$$Y_1 = f\ (x_1, x_2, x_3, x_4, x_5) \tag{1}$$

and

$$Y_2 = f\ (x_1, x_2, x_3, x_4, x_5) \tag{2}$$

the proposed governing equations in algebra are given as

$$Y_1 = a_1x_1 + a_2x_2 + a_3x_3 + \ldots a_nx_n \tag{3}$$

$$Y_2 = b_1x_1 + b_2x_2 + b_3x_3 + \ldots b_nx_n \tag{4}$$

In this case, Y_1 and Y_2 are objective functions and a_i and b_i are constants to be determined, where there are n concomitant variables x_i, and they represent the weight or strength of dependency of Y_1 and Y_2 on each x_i.

Furthermore, investigation of the interdependency of Livestock (Y_2) and Crop (Y_1) took a quadratic regression equation of the form, depending on the level of the adjusted R^2:

Linear, $Y_1 = a + b_1x_1 + b_2x_2 + \ldots b_nx_n$ (5)

Double log, $Ln\ Y_1 = a + b_1\ Lnx_1 + b_2\ Ln\ x_2 + \ldots + b_n\ Ln\ x_n$ (6)

Semilog, $Ln\ Y_1 = a + b_1x_1 + b_2x_2 + \ldots b_nx_n$ (7)

Exponential, $Y_1 = a + b_1\ Lnx_1 + b_2\ Ln\ x_2 + \ldots + b_n\ Ln\ x_n$ (8)

$Y_2 = f\ (Y_1)$ (9)

Using the above basis and relating it to management systems in this study, the following relationships exist for:

Management 1, $Y_1 = f\ (x_1, x_2, x_4);\ Y_2 = 0$ (10)

Management 2, $Y_1 = f\ (x_1, x_2);\ Y_2 = 0$ (11)

Management 3, $Y_1 = f\ (x_1, x_2, x_3);\ Y2 = f\ (x_1, x_2, x_4, x_5)$ (12)

Specifications on the use of these equations/this model:

Firstly, the governing/general equations are 3 and 4, described above and presented in the subsequent tables as:

$Y_1 = a_1x_1 + a_2x_2 + a_3x_3 + \ldots a_nx_n$

$Y_2 = b_1x_1 + b_2x_2 + b_3x_3 + \ldots b_nx_n$

Note that each treatment contains no extra constant. They represent what are called objective functions in linear optimisation or linear combinations in algebra. The coefficients *a1, a2, a3 or b1, b2, b3* show the contribution of X_1 X_2 X_3, which could be either positive or negative to the objective functions Y_1 or Y_2. It does not mean that they have negative mathematical values.

Secondly, the regression analysis $Y = f(X)$ must have a constant coefficient of the regression. It shows the dependency of *Y* on *X*. The rate of increase or decrease in *Y* with respect to *X* can be deduced. Similarly, the turning point could be either maximum or minimum in the quadratic regression.

8.4 Scenario analysis of applied management systems

Using equation 10 for management system *M1*, the dependence of maize grain yield is directly proportional to weed incidence, soil nitrogen, contributions by the legumes and no compost in this system, i.e. $X_3 = 0$. Likewise, equation 11 is suited for management system *M2*, where the dependence of crop productivity is related to weed and soil nitrogen contributions only. Compost and crop residues do not come into this system, since legume residues are often taken out of the field, $X_3 = 0$ *and* $X_4 = 0$. In more complex systems, equation 12 is applicable to management system *M3,* where full integrations of crop-livestock exist, crop production Y_1 is dependent on three entities: weeds, soil nitrogen and compost generated by feeding the rams. Livestock development Y_2 is also proportional to three entities, namely weeds, soil nitrogen and maize stover fed to the rams.

8.5 Results

2001 case study

Data from the main experiment in 2001, showed that crop production depended largely on weeds, soil nitrogen and livestock compost contributions, although this varied across the three management systems. For instance, the equation describing management system *M1* showed that both weeds and soil contribute positively to crop production, but legumes had a negative effect (Table 8.1). It could be argued that this is a pooled average. Another possibility is the low phosphorus content of the soil. Legumes use a lot of phosphorus and may cause phosphorus deficiencies, in spite of phosphorus fertiliser being added. Moreover, the negative contribution from the natural vegetation could be strong enough to significantly influence the weight of the effect of the other legumes in the equation, as shown in Table 8.1.

The situation as seen in management system *M2* is a direct way of explaining the real situation, which is that is soil fertility significantly influenced crop productivity, while weeds had a negative effect on crop productivity. The argument in this situation is that the system became complex when more than two components were in the system. Interestingly, the situation under management system *M3* showed that the factors of weeds, soil and compost contributed positively to crop productivity. In relation to the performance under management system *M2* where compost was lacking, it seems the contribution of livestock compost in the system outweighed the negative effect weeds might have contributed.

2002 case study

In 2002, results from both the two study areas made the modelling more complex. However, in spite of the differences in terms of length of fallow with legumes and cropping history, the same patterns were obtained for the two localities, but individual contributions varies between the localities and management systems (Table 8.2). The only significant trend observed was that soil fertility played a consistent positive role in crop production. Weeds, legumes and compost had varying effects on crop production, and most of these effects were relatively small.

Results presented in Table 8.2 showed no differences between the two rotation systems for the management systems under study. The only difference is seen in management system *M3*, where maize stover contributed negatively for livestock improvement in *2yrL1yrM*, compared to its positive contribution in *1yrL2yrM*. The equation indicated that the contribution of soil nitrogen was so significant that it made contributions from other components redundant. Using this argument, one can assume that because the level of soil nitrogen was lower in *1yrL2yrM*, maize stover had to complement the energy source.

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Table 8.1 Results showing the crop interactions in the presence of weeds, soil nitrogen, livestock compost and herbaceous legumes, using the 2001 data from the experimental farm in the northern Guinea savannah.

	Level	CROP Y_1	LIVESTOCK Y_2
1	Management 1	$Y_1 = 0.17x_1 + 13.0x_2 - 0.18x_4$	*NA*
2	Management 2	$Y_1 = -0.13x_1 + 11.52x_2$	*NA*
3	Management 3	$Y_1 = 0.53x_1 + 3.94x_2 + 0.22x_3$	*NA*

NA = not applicable
Crop productivity = Y_1 in kg and Livestock weight gain = Y_2 in kg.
Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3; in kg; Herbaceous legumes = x_4 in kg

Table 8.2 Results showing the crop interactions in the presence of weeds, soil nitrogen, livestock compost and herbaceous legumes using the 2002 data from the experimental farm in the northern Guinea savannah.

1yrL2yrM

	Level	CROP Y_1	LIVESTOCK Y_2
1	Management 1	$Y_1 = -0.5x_1 + 26.36x_2 - 0.53x_4$	*NA*
2	Management 2	$Y_1 = -0.84x_1 + 8.87x_2$	*NA*
3	Management 3	$Y_1 = -0.2x_1 + 7.19x_2 - 0.62x_3$	$Y_2 = -0.24x_1 + 1.4x_2 - 0.63x_4 + 0.25x_5$

2yrL1yrM

	Level	CROP Y_1	LIVESTOCK Y_2
1	Management 1	$Y_1 = -0.44x_1 + 7.316x_2 - 0.33x_4$	*NA*
2	Management 2	$Y_1 = -0.14x_1 + 7.2x_2$	*NA*
3	Management 3	$Y_1 = -0.19x_1 + 18.7x_2 - 0.16x_3$	$Y_2 = -0.87x_1 + 3.87x_2 - 0.65x_4 - 0.42x_5$

NA = not applicable
1yrL2yrM = portion planted to maize in 2002 after 1-year of herbaceous legumes followed. The side is characterised by 2 years of continuous cropping
2yrL1yrM = portion planted to maize in 2002 after 2 years of continuous planting of herbaceous legumes
Crop productivity = Y_1 in kg and Livestock weight gain = Y_2 in kg.
Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3; in kg; Herbaceous legumes = x_4 in kg; Maize stover = x_5 in kg.

8.6 Models for individual management systems as influenced by selected legumes

In this pilot case study, the 2002 set of data was used in estimating the effects contributed by these components with appropriate equations as given in equations 10, 11 and 12. The predictions are made to assess the effect of each of the components namely, weeds, soil, livestock compost, herbaceous legumes, and maize stover for herbaceous legumes and natural vegetation, and the management systems.

8.6.1 Management system 1

Equation 10 presents a situation where a smallholder mixed-legume farming system relies solely on nitrogen contributions from legumes planted in the field for high grain production. Similarly, residues of legume and maize stovers are applied as mulch primarily to control weed incidence and improve soil conditions. The equations presented in Table 8.3 showed that different components contributed differently to the overall crop production for different herbaceous legumes. For instance, in term of objective functions, weeds contributed positively for *C. pascuorum, V. unguiculata* and *A. hypogaea* whereas soil nitrogen contributed negatively for *A. histrix* (Table 8.3). Legume residues applied to the soil had positive contributions for *C. pascuorum, A. histrix, V. unguiculata* and *A. hypogaea.*

8.6.2 Management system 2

Equation 11 represents a system where farmers rely on nitrogen fixation from herbaceous legumes to enhance crop production. Aboveground residues in the system are moved out of the field for various purposes. In relation to the presence of weeds in the system, the equation (Table 8.4) indicates that weeds contributed negatively to crop production. A clear indication of this is found in natural vegetation, *A. histrix, G. max.* and *S. guianensis*, whereas the effect of weeds was not pronounced for *C. pascuorum, V. unguiculata* and *A. hypogaea*. This would seem to indicate that these legumes were probably able to overcome the stress caused by weeds in the systems. Soil nitrogen contributed positively for all the legumes, except for natural vegetation (Table 8.4). Soil nitrogen effects for natural vegetation plots were negative, which is most probably due to the absence of nitrogen fixing agents (nodulation) responsible for converting atmospheric nitrogen in the system (Table 8.4).

8.6.3 Management system 3

Table 8.5 presents regression equations for management system *M3* in 2002. In this system, crops and livestock played significant roles in partitioning the various components. It is interesting to note that the dependency of both livestock and crop production on weeds, soil, livestock compost, legumes and maize stover varies significantly among the selected legumes and natural vegetation. For example, both weeds and soil nitrogen contributed positively to crop productivity for *C. pascuorum*. In the case of *V. unguiculata*, only compost contributed positively to crop productivity. Similarly, using the same legumes to assess livestock management, improved livestock weight gain was enhanced by the presence of maize stovers in the system for *C. pascuorum*, while feeding *V. unguiculata* to the rams positively influenced livestock output. The interactive dependency could be argued for other legumes in different management systems. An example is *S. guianensis*, where all the factors of weeds, soil nitrogen and livestock compost contributed positively to crop productivity, whereas the trend was reversed for *G. max*, where these factors tended to be negative (Table 8.5).

8.6.4 Interactive pattern in Crop-Livestock systems

A quadratic regression using equation 9 showed the interactive pattern for livestock weight gain and crop productivity. Data collected in 2002 was also used for this aspect and the results are presented in Table 8.6. Regression equations indicate that absolute dependency of livestock on crop production was significantly enhanced under *A. hypogaea,* followed by *G. max, A. histrix, S. guianensis, C. pascuorum and V. unguiculata*.

Table 8.3 Objective functions showing the crop interactions in the presence of weeds, soil nitrogen, and herbaceous legumes, using the 2002 data from *M1* on the experimental farm in the northern Guinea savannah.

Level	Herbaceous legumes	CROP Y_1	LIVESTOCK Y_2
1	*C. pascuorum*	$Y_1 = 0.01x_1 + 168.23x_2 + 0.060x_4$	$Y_2 = 0$
2	*V. unguiculata*	$Y_1 = 0.01x_1 + 47.29x_2 + 1.27x_4$	$Y_2 = 0$
3	*A. hypogaea*	$Y_1 = 0.02x_1 + 58.19x_2 + 0.004x_4$	$Y_2 = 0$
4	*A. histrix*	$Y_1 = -0.04x_1 - 48.02x_2 + 0.06x_4$	$Y_2 = 0$
5	*G. max*	$Y_1 = -0.01x_1 + 25.83x_2 - 3.22x_4$	$Y_2 = 0$
6	*S. guianensis*	$Y_1 = -0.009x_1 + 1.32x_2 - 0.05x_4$	$Y_2 = 0$
7	N. vegetation	$Y_1 = -0.006x_1 + 19.02x_2 - 0.27x_4$	$Y_2 = 0$

Crop productivity = Y_1 in kg and Livestock weight gain = Y_2 in kg.
Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3; in kg; Herbaceous legumes = x_4 in kg; Maize stover = x_5 in kg.

Table 8.4 Objective functions showing the crop interactions in the presence of weeds and soil nitrogen, using the 2002 data from *M2* on the experimental farm in the northern Guinea savannah.

Level	Herbaceous legumes	CROP Y_1	LIVESTOCK Y_2
1	*C. pascuorum*	$Y_1 = 0.002x_1 + 84.69x_2$	$Y_2 = 0$
2	*V. unguiculata*	$Y_1 = 0.006x_1 + 22.37x_2$	$Y_2 = 0$
3	*A. hypogaea*	$Y_1 = 0.01x_1 + 37.05x_2$	$Y_2 = 0$
4	*A. histrix*	$Y_1 = - 0.002x_1 + 104.19 x_2$	$Y_2 = 0$
5	*G. max*	$Y_1 = - 0.06x_1 + 17.94x_2$	$Y_2 = 0$
6	*S. guianensis*	$Y_1 = - 0.01x_1 + 9.12x_2$	$Y_2 = 0$
7	N. vegetation	$Y_1 = - 0.06x_1 - 25.98x_2$	$Y_2 = 0$

Crop productivity = Y_1 in kg and Livestock weight gain = Y_2 in kg.
Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3; in kg; Herbaceous legumes = x_4 in kg; Maize stover = x_5 in kg.

Table 8.5 Results showing the crop interactions in the presence of weed, soil nitrogen, livestock compost and herbaceous legumes, using the 2002 data from *M3* on the experimental farm in the northern Guinea savannah.

Level	Herbaceous legumes	CROP Y_1	LIVESTOCK Y_2
1	*C. pascuorum*	$Y_1 = 0.03x_1 + 5.98x_2 - 0.53x_3$ $R^2 = 0.92$	$Y_2 = -0.12x_1 - 21.48x_2 - 1.61x_4 + 0.67x_5$
2	*V. unguiculata*	$Y_1 = -0.01x_1 - 109.3_2 + 1.56x_3$ $R^2 = 0.92$	$Y_2 = +0.14x_1 - 190.3x_2 + 2.48x_4 - 0.13x_5$
3	*A. hypogaea*	$Y_1 = -0.0009x_1 + 48.0x_2 - 0.23x_3$ $R^2 = 0.92$	$Y_2 = -0.23x_1 + 18.56x_2 - 1.01x_4 - 0.36x_5$
4	*A. histrix*	$Y_1 = -- 0.02x_1 + 21.02x_2 - 0.19x_3$ $R^2 = 0.49$	$Y_2 = -0.2x_1 + 3.58x_2 + 0.41x_4 + 0.42x_5$
5	*G. max*	$Y_1 = -0.14x_1 - 43.34x_2 - 0.01x_3$ $R^2 = 0.78$	$Y_2 = +0.33x_1 + 1.48x_2 - 3.24x_4 - 0.57x_5$
6	*S. guianensis*	$Y_1 = +0.09x_1 + 17.31x_2 + 0.52x_3$ $R^2 = 0.89$	$Y_2 = +0.57x_1 - 18.35x_2 - 0.45x_4 + 0.82x_5$
7	N. vegetation	$Y_1 = +0.02x_1 + 69.31x_2 - 1.0x_3$ $R^2 = 0.62$	$Y_2 = +0.11x_1 + 0.18x_2 - 0.12x_4 + 0.23x_5$

Crop productivity = Y_1 in kg and Livestock weight gain = Y_2 in kg.
Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3; in kg; Herbaceous legumes = x_4 in kg; Maize stover = x_5 in kg.

Table 8.6 Quadratic regression equation showing the relationships between Livestock and Crops, using the 2002 data from *M3* on the experimental farm in the northern Guinea savannah.

Level	Herbaceous legumes	$Y_2 = f(Y_1)$
1	*C. pascuorum*	$Y_2 = 10.25 - 4.92\, Y_1 + 0.76\, Y_1^2$
2	*V. unguiculata*	$Y_2 = -0.64 + 2.47\, Y_1 - 0.39\, Y_1^2$
3	*A. hypogaea*	$Y_2 = 0.77 + 1.6\, Y_1 - 0.17\, Y_1^2$
4	*A. histrix*	$Y_2 = 0.68 + 1.1\, Y_1 - 0.14\, Y_1^2$
5	*G. max*	$Y_2 = 12.85 - 4.94\, Y_1 + 0.65\, Y_1^2$
6	*S. guianensis*	$Y_2 = -2.73 + 3.33\, Y_1 - 0.45\, Y_1^2$
7	N. vegetation	$Y_2 = -0.59 + 4.94\, Y_1 + 0.65\, Y_1^2$

Crop productivity = Y_1 in kg and Livestock weight gain = Y_2 in kg.
Weed = x_1 in kg; Soil = x_2 g kg^{-1}; Livestock compost = x_3; in kg; Herbaceous legumes = x_4 in kg; Maize stover = x_5 in kg.

8.7 Conclusions

Focusing principally on integrated crop-livestock systems in this study, the objective functions in the equations for each of the components and management systems, present different scenarios for several systems. Data and equations relating to objective functions presented in Tables 8.1 to 8.6 could be seen as predictive tools to solve most of the complicated situations often faced by peasant farmers.

However, it is necessary to note the difference between the results suggested by these models and what was actually found in practice. In management system *M1*, with *in situ* crop residues, weeds and legume species could contribute negatively to crop development in 'particular situations'. Soil nitrogen had a positive effect on crop production (Table 8.2). This can be seen in real life, because farmers often complain of weeds as their major problem. Similarly, the absence of non nitrogen-fixing species in farmers' field could hinder crop production. The same deductions could be inferred for other management systems under different legume species as expressed in equations (Tables 8.2 to 8.5).

The importance of this technique may not be appreciated now, considering the level of complexity involved. However, the involvement of herbaceous legumes in the system gave better results than natural vegetation in the regression equation. Likewise, the presence of manure in the system is of great importance. Wherever it tended to contribute negatively, the values are always small, -0.01 to -0.05, compared to the high ranges observed for weeds, for example -1.0 to –5.8. It is envisaged that strategies considered would intensify natural resource management and could be adopted by peasant farmers in the region.

In summary, these assumptions need to be validated under field conditions, before they can be used as an advisory tool to promote the integration of crop and livestock systems.

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Chapter 9

Summary and conclusions

Herbaceous legumes offer an attractive system in the context of this study, being able both to provide forage for livestock and at the same time improve soil fertility, promoting a sustainable use of land resources. In this thesis, new methods, such as a holistic approach to natural resources, for example soil fertility, weed dynamics and livestock management components for sustainable crop–livestock integration, were evaluated on-station. These effects were studied independently from one another, with the following emphasis:

- Agronomic evaluation of herbaceous legumes with respect to restoration of soil fertility, weed management, crop and livestock sustenance.
- Livestock feeding with herbaceous legumes.
- Soil weed-seed assessment.
- Involvement of management systems to maximise contributions to crop and livestock productivity.

To actualise the above goals, the main experiment was carried out at Zaria, in the northern Guinea savannah of Nigeria. A smaller, secondary experiment, with fewer management systems was carried out simultaneously at two localities with different climatic conditions, namely Zaria and Ibadan (derived savannah). Study sites in these localities were on research farms at the

National Animal Production Research Institute (NAPRI), Zaria and the International Institute of Tropical Agriculture (IITA), Ibadan. Herbaceous legumes tested were *Aeschynomene histrix, Glycine max, Centrosema pascuorum, Vigna unguiculata, Stylosanthes guianensis, Arachis hypogaea* and the natural vegetation that served as control. These legumes were evaluated under three management systems, *viz.*: *M1*, crop residues left *in situ*, *M2*, crop residues exported out of the field and *M3*, crop residues fed to livestock, manure/compost returned to the field for subsequent cropping.

The most important results from these experiments are given below:

- ► The herbaceous legumes tested are potentially suitable for integration into sown pasture. They established well in all regions. Although forage biomass was higher in the derived savannah than the northern Guinea savannah, their performance in the northern Guinea savannah varied according to fallowing the cropland for different lengths. Biomass yield after two years of continuous cropping was the highest for *S. guianensis*, followed by *C. pascuorum, A. histrix* (forage legumes) and even for *G. max, V. unguiculata* and *A. hypogaea* (grain legumes).
- ► Crude protein in feed residues ranged from 170g kg^{-1} DM in *A. hypogaea* to 62.4g kg^{-1} DM in *A. histrix*. Dry matter digestibility was rated high for *S. guianensis, G. max* and *A. histrix*, while the least digestible material was that of *A. hypogaea*, 177.6g kg^{-1} DM.

- ► The impact of dual-purpose grain legumes, *V. unguiculata, A. hypogaea and G. max*, was noted in the provision of grains and forages. They are preferred to forage legumes.
- ► Weed infestation showed a consistently higher rate of infestation on natural vegetation plots than for the herbaceous legume plots.
- ► It was evident that *S. guianensis* suppressed weeds better than other legumes. Ranking from highest to lowest, their potentials are *S. guianensis, C. pascuorum, V. unguiculata, G. max, A. hypogaea* and *A. histrix*.
- ► Weed seed bank studies revealed that, after a short fallow of one year, sedges, *Oldenlandia corymbosa* and *Ageratum conysoides* dominated the seed bank. Their status and seed composition changes as the length of fallow increases, indicating that planted legumes played a significant role on weed seed bank, probably due to smothering effects.
- ► Livestock weight gain was improved when they were fed with herbaceous legume-based diets. For instance, rams fed with *A. hypogaea* gained 85.7g day^{-1}, followed by rams fed with *S. guianensis, C. pascuorum, G. max, A. histrix, V. unguiculata,* and least for natural vegetation.
- ► Objective functions in linear optimisation, or linear combinations in algebra, were developed for the three management systems considered in this study. However, the models need to be validated

under field conditions, before they can be used as an advisory tool to promote the integration of crop-livestock systems.

- Overall rankings indicate that *G. max* performed best of all legumes, followed by *S. guianensis*, ranked second, and *A. hypogaea*, third. In relation to the specific legume groups, *S. guianensis* performed better than the other two forage legumes, while *G max* also performed better than the other two grain legumes tested (Table 9.1).
- The suitability of different legumes for the management systems tested, with regard to the best forage biomass, forage grain production, contribution to soil fertility and weed suppression, livestock performance and compost production for subsequent cropping, are summarised in Table 9.2 for quick reference.

This study showed that ample opportunities are available for improving overall productivity and resources through integration and complementing crop and livestock productions to provide a sustainable intensification of agriculture in the moist savannah of Nigeria.

Table 9.1. *Overall performance of selected herbaceous legumes in cognisance of contributions made by all components in the system.*

Herbaceous legumes	Soil cove-rage	Rege-neration	Grain yield.	Forage biom.	Weed Suppr-ession	Mineral N	Mineral P	Organic Matter	DMD	Overall perfor-mance	Ranking	Type of Legume	Ranking based on type of HL
A. histrix	1	1	NA	2	2	5	6	3	5	25	3rd	Forage	2nd
C. pascuorum	3	2	NA	3	3	4	3	2	2	22	5th	Forage	3rd
S. guianensis	2	3	NA	4	2	2	6	5	4	28	2nd	Forage	1st
A. hypogaea	4	NA	2	5	3	6	5	1	1	27	2nd	Grain	2nd
V. unguiculata	6	NA	1	4	1	1	3	4	3	23	4th	Grain	3rd
G. max	5	NA	3	6	4	3	4	6	6	37	1st	Grain	1st

NA= Not applicable
DMD= Dry matter digestibility
<u>Scoring:</u>
1 = Lowest performance
6 = Highest performance

Table 9.2 *Suitability of different legumes for management systems studied.*

Index	*A. hypogaea*	*G. max*	*V. unguiculata*	*S. guianensis*	*C. pascuorum*	*A. histrix*
Forage biomass (mg ha^{-1} dry matter)	Generally performed well and ranked second to soybean. Good biomass on management systems *M1* and *M3* respectively	The best among grain legumes. Good biomass on management systems *M1* and *M3* respectively	Performed poorly due to late planting	The best among forage legumes	Produced higher forage biomass and ranked second among the forage legumes	Biomass performance varied across the year
Forage grain production (mg ha^{-1} Grain)	Ranked second after soybean. Rodents attacked the pods before harvest.	Higher grain observed for soybean. Most grains were lost at harvest due to shattering of the seeds.	Low grain yield at harvest. Grain yield are generally poor due to late planting and disease attack on the plant. Balancing grain harvest before forage is cut needs to be implemented	NA	NA	NA
Forage quality based on crude protein contents (g kg^{-1} Grain)	Groundnuts have the highest crude protein in the aboveground biomass	Soybeans ranked third among the tested herbaceous legumes	The least amount of crude protein was realised on cowpea leaves	Crude protein ranked fifth among the tested herbaceous legumes	Crude protein ranked fourth in the series	Ranked second in crude protein contents among the tested herbaceous legumes
Contribution to soil fertility	Not measured directly, see maize yield	Not measured directly, see maize yield	Not measured directly, see maize yield	Not measured directly, see maize yield	Not measured directly, see maize yield	Not measured directly, see maize yield

Table 9.2 continues.

Index	*A. hypogaea*	*G. max*	*V. unguiculata*	*S. guianensis*	*C. pascuorum*	*A. histrix*
Maize yield (mg ha^{-1} Grain)	Higher maize grain yield was realised. Maize yield was positively influenced by the legume	Slightly lower than the best maize grain yield observed. Maize yield was positively influenced by the legume	Maize yield was influenced by the legume but the yield ranked fifth on the list	Lower maize grain but not significantly different from other forage legumes. There was variation in maize yield across the year. Maize yield was positively influenced by the legume	Maize yield on ranked third on the list and this was influenced by the legume	Maize ranked fourth on the list and this was influenced by the legume
Mulching/weed suppression	More weeds as a result of improved soil fertility	Weed biomass higher after one year fallow and reduced subsequently	Weed biomass was high, indicative of positive contribution to soil fertility	Weed biomass was high, indicative of positive contribution to soil fertility	Has mulching potentials. More weeds on plots without this legume	Preferred to be left on the field than fed to livestock
Livestock performance (live weight gain, g day^{-1})	Improved live weight gain	Improved live weight gain	Animals failed to gain weight	Positive effect on livestock performance	Positive effect on livestock performance	Negative effect on livestock performance
Compost production (g $sheep^{-1}$ day^{-1})	High manure production. Manure returned enhanced the performance of maize yield	Manure returned enhanced the performance of maize yield	Low manure production	Positive effect on manure production	Positive effect on manure production	Negative effect on manure production

Constraints and research needs were identified concerning the following aspects:

- ► The present study was carried out on-station, thereby reducing the chances of inference and practice at farmers' level; thus, there is need to validate these finding on farmers' fields.
- ► Due to its complexity and dynamic nature, management systems were related to systems that simulated the situations of farmers in intensifying crop-livestock systems. The search for supplementary management systems for optimum output has to continue.
- ► There could be reservations regarding models presented in this thesis, since the original idea was not to give data for models, but in the course of the experiment, relevant data suitable for modelling were collected. Modelling trials also need to be planned, to measure if the actual response of treatments correlates with the predicted responses of the models. Models presented in this thesis need to be validated in real situations.
- ► The single-site, single-year data presented in the study could be viewed as flaws in the experimental set-up, but replications and several sampling points considered could reduce experimental errors. Future research could be carried out simultaneously at many sites, over a longer period.

Glossary

1 List of weed species in the study sites.

Codes	Weed species	*Abbreviation used in the ordination diagram*
1	*Acacia nilotica*	Aca nil
2	*Acalypha sp*	Aca spc
3	*Acanthospermua hispidum*	Aca his
4	*Aechynomene histrix*	Aec his
5	*Ageratum conysoide*	Age con
6	*Alysicarpus spp*	Aly spc
7	*Amaranthus spinosus*	Ama spi
8	*Amaranthus viridis*	Ama vir
9	*Aspilia africana*	Asp afr
10	*Borreria stachydea*	Bor sta
11	*Blumea aurita*	Blu aur
12	*Brachiaria jubata*	Bra jub
13	*Broad leaves*	Bro lea
14	*Celosia trigyna*	Cel tri
15	*Centrosema pubscens*	Cen pub
16	*Chamaecrista rotundifolia*	Cha spc
17	*Chrotolaria spp*	Chr spc
18	*Chrysanthellum americanum*	Chr ame
19	*Cucurbitaceae*	Cir spc
20	*Commenlina benghalensis*	Com ben
21	*Commenlina nigritana*	Com nig
22	*Corchorus trilocularis*	Cor tri
23	*Cynodon dactylon*	Cyn dac
24	*Dactygloctenium aegyptium*	Dac aeg
25	*Degitaria horozontalis*	Deg hor
26	*Degitaria nuda*	Deg nud
27	*Desmodium tortuosum*	Des tor
28	*Eclipta prostrata*	Ecl pro
29	*Eleusine indica*	Ele ind
30	*Eragrotis tenella*	Era ter
31	*Eragrotis turgida*	Era tug
32	*Brachiaria leta*	Bra let
33	*Euphorbia hirta*	Eup chr
34	*Euphorbia hyssopifolia*	Eup his
35	*Euphorbia heterophylla*	Eup lie
36	*Fimbrystylis hispidula*	Fim his
37	*Glycine maximum*	Gly max
38	*Grasses species*	Gra spc
39	*Hyparrhenia sp*	Hyp spc
40	*Ipomea involucrata*	Ipo inv
41	*Ipomea eriocarpa*	Ipo eri
42	*Leuca martinicensis*	Leu mar
43	*Ludwigia abyssinica*	Led aby
44	*Mitracarpus villosus*	Mit ull

45	*Nelsonia canesteen*	Nel can
46	*Oldenlandia corymbosa*	Old cor
47	*Paspalum orbiculare*	Pas orb
48	*Physalis angulata*	Phy ang
49	*Physalis micrantha*	Phy mir
50	*Boerhavia diffusa*	Boe dif
51	*Portulaca olareacea*	Por ola
52	*Schwvenkia americana*	Sch ame
53	*Sedges*	Sed spc
54	*Senna obtusifolia*	Sen obt
55	*Seteria barbata*	Set bar
56	*Seteria palide fusca*	Set pal
57	*Sida acuta*	Sid acu
58	*Sida cordifolia*	Sid cor
59	*Solanum nigrum*	Sol nig
60	*Lindernia sp*	Lin spc
61	*Starchytapheta augustifolia*	Sta aug
62	*Stylochiton sp*	Sty spc
63	*Stylosanthes guinensis*	Sty gui
64	*Tephrosia elegan*	Tep ele
65	*Tridax procumben*	Tri pro
66	*Gomphrena celosiodes*	Gom cel
67	*Vernonia galamensis*	Ver gal
68	*Vernonia nigrihana*	Ver nig
69	*Vigna*	Vig spc
70	*Penisetum polystachion*	Pen pol
71	*Mariscus alternifolius*	Mar alt
72	*Indigofera spicata*	Ind spi
73	*Croton lobata*	Cro lab
74	*Ipomea aquatica*	Ipo aqu
75	*Chloris pilosa*	Cho pil
76	*Scoparia dulcis*	Sco dul
77	*Andropogon gayanus*	And gay
78	*Sporobulus pyramidalis*	Spo pyr
79	*Hibiscus*	Hib spc
81	*Senna hirsuta*	Sen hir
82	*Passiflora foetida*	Pas foe
83	*Talinum triangularre*	Tal tri
84	*Synedrella nodiflora*	Syn nod
85	*Merremia aegyptia*	Mer aeg
86	*Panicum maximum*	Pan max
87	*Alternatheria sessilis*	Alt ses
88	*Desmodium scorpirus*	Des sco
89	*Cleome viscosa*	Cle vis
92	*Sesbania pubescens*	Ses pub
94	*Chromoleana odorata*	Cro odo
95	*Arachis hypogea*	Ara hyp
97	*Diodea scandes*	Dio sca
98	*Kylhiangia bulbosa*	Kyl bul
99	*Sporiduss miobri*	Spo mio
100	*Poaceae*	Poa spc

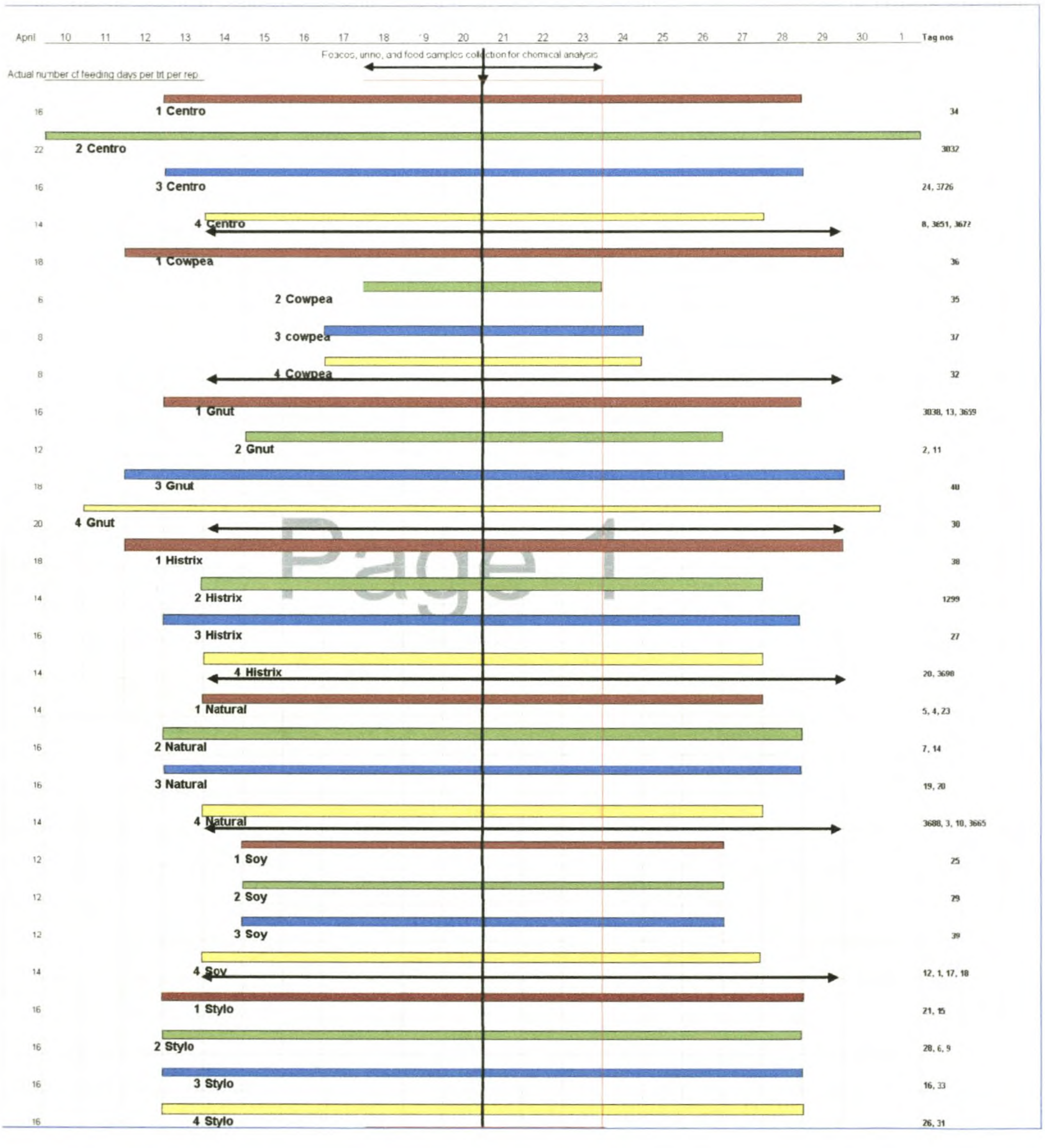
101	*Polygate arenara*	Pol are
102	*Rohbocilia cocho*	Roh coc
103	*Luffa aegypti*	Luf aeg
104	*Spermacoce stachydea*	Spe sta
105	*Watherria indica*	Wea ind

2 Annex 1: Acronyms used in text

ABU	Amadu Bello University, Zaria, Nigeria
AEZ	Agro ecological zone
BMZ	Bundesministerium fur Wirtchaftliche Zusammenarbeit und Entwicklung, Germany (Ministry of Economic Cooperation and Development)
CSA	Central and South America
DS	Derived Savanna
EA	East Asia
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit (German Agency for Technical Cooperation)
IAR	Institute of Agricultural Research, Zaria, Nigeria
IITA	International Instituete of tropical Agriculture, Nigeria
ILCA	International Livestock Center for Africa
ILRI	International Livestock Reesarch institute, Kenya
INRAB	Institut National de Recherches Agricoles du Benin, Republic du Benin
LGP	Length of growing period
NAPRI	National Animal Production Research Institute, Zaria, Nigeria
NGS	Northern Guinea Savanna
NIS	Newly Independent States
PPR	Peste des Petits Ruminants
SA	South Asia
SEA	South-East Asia
SSA	Sub-Saharan Africa
US	University of Stellenbosch, Cape Province, South Africa,
WANA	West Asia–North Africa

Appendix

Appendix 1 Feed rationing based on available feeds residues during the feeding trail in Zaria, 2002.



Appendix 2 Climatologically data in Zaria, 2000-2002

Syear	Sloc	Month	Rainfall	Max. RH	Min. RH	Min. Temp	Max. Temp	Mean Temp	Sun shine hrs
2000	Zaria	Jan	0	30	20.8	17.6	32.6	25.1	8.2
2000	Zaria	Feb	0	16.9	12.6	16.7	38.4	27.6	6.6
2000	Zaria	Mar	0	15.1	11.7	21.5	36.9	29.2	6.3
2000	Zaria	Apr	0	53	22.2	25.1	39.5	32.3	8.2
2000	Zaria	May	149.5	64.1	37.7	25	37	31	7.9
2000	Zaria	Jun	193.4	82.1	61.2	22.5	31.8	27.1	7
2000	Zaria	Jul	221.3	85.9	71.5	22.2	30.1	26.1	5.9
2000	Zaria	Aug	245.2	87.9	78.5	21.5	29.3	25.4	5.3
2000	Zaria	Sep	182.1	82.4	73.1	22	31	26.5	6.4
2000	Zaria	Oct	78	71.2	58.6	20.2	32.6	26.4	7.4
2000	Zaria	Nov	0	37	29.5	16	33.1	24.6	8.4
2000	Zaria	Dec	0	33	20	17	31	24	7.9
2001	Zaria	Jan	0	24	13.6	14.7	30.8	22.7	8.3
2001	Zaria	Feb	0	21.2	16.4	17.2	32.4	24.8	5.9
2001	Zaria	Mar	0	18.5	11.3	21.8	37.3	29.5	7.3
2001	Zaria	Apr	83.9	52.4	36.5	24.1	36	30	6.9
2001	Zaria	May	160.3	75.7	48.6	24.2	34.5	29.3	8.1
2001	Zaria	Jun	177.7	81.2	63.9	22.8	31.8	27.3	7.1
2001	Zaria	Jul	267.8	87.2	71	22	30.4	26.2	5.9
2001	Zaria	Aug	360.9	89.9	79.8	22.1	29.7	25.9	4
2001	Zaria	Sep	271.7	86.7	77.5	22	31	26.5	6
2001	Zaria	Oct	0	63	47.9	20	32	26	7.1
2001	Zaria	Nov	0	28	22	16	33	24.5	8.6
2001	Zaria	Dec	0	24	17	17	33.7	25.3	8.4
2002	Zaria	Jan	0	23.2	17	15.2	27.7	21.5	4.5
2002	Zaria	Feb	0	18	14	18.6	32.5	25.5	6.5
2002	Zaria	Mar	0	29	22.8	23	37.1	30.1	6.2
2002	Zaria	Apr	60.9	68	45	25.6	37.3	31.5	6.3
2002	Zaria	May	10.6	79.4	57.4	26	37.4	31.7	7.8
2002	Zaria	Jun	133.1	85.7	75.2	23.2	33.1	28.1	7.2
2002	Zaria	Jul	229	90.1	87.4	22.1	31.1	26.6	6
2002	Zaria	Aug	201.4	90.6	90.6	22.3	29.8	26.1	5.5
2002	Zaria	Sep	193.9	88.7	90	22.3	31.1	26.7	7
2002	Zaria	Oct	125.2	86.6	86.1	21.2	31.6	26.4	6.2
2002	Zaria	Nov	0	67.9	55.5	17.4	30.6	24	7.4
2002	Zaria	Dec	0	65	38.4	15.4	31.6	23.5	8.4

Appendix 3 Climatologically data in Ibadan, 2000-2002

Syear	Sloc	Month	Rainfall	Max. RH	Min. RH	Min. Temp	Max. Temp	Mean Temp	Sun shine hrs
2000	Ibadan	Jan	11.70	98.79	43.05	22.05	33.17	27.61	5.90
2000	Ibadan	Feb	0.00	84.81	21.38	19.74	34.69	27.22	-9.00
2000	Ibadan	Mar	97.00	97.98	32.33	22.43	35.75	29.09	-9.00
2000	Ibadan	Apr	124.50	99.00	60.64	22.93	32.84	27.88	-9.00
2000	Ibadan	May	88.30	99.02	63.41	22.64	31.98	27.31	-9.00
2000	Ibadan	Jun	165.40	99.00	67.73	21.73	30.15	25.94	-9.00
2000	Ibadan	Jul	233.10	99.11	73.38	21.42	28.44	24.93	-9.00
2000	Ibadan	Aug	253.20	99.03	76.51	21.36	27.82	24.59	-9.00
2000	Ibadan	Sep	236.20	99.00	71.76	22.05	29.48	25.77	-9.00
2000	Ibadan	Oct	106.30	98.90	63.78	22.06	30.77	26.42	-9.00
2000	Ibadan	Nov	0.00	99.00	49.28	23.23	32.88	28.05	-9.00
2000	Ibadan	Dec	0.00	97.69	36.78	20.61	33.21	26.91	-9.00
2001	Ibadan	Jan	0.00	98.27	35.91	20.86	33.48	27.17	7.53
2001	Ibadan	Feb	11.90	92.36	25.86	21.03	35.37	28.20	7.29
2001	Ibadan	Mar	69.30	98.83	42.02	23.42	35.25	29.33	7.10
2001	Ibadan	Apr	93.80	99.03	56.99	22.79	33.01	27.90	6.46
2001	Ibadan	May	154.80	99.01	64.14	22.46	31.92	27.19	7.23
2001	Ibadan	Jun	328.00	99.00	68.89	21.59	30.33	25.96	6.31
2001	Ibadan	Jul	177.80	99.03	73.62	22.24	28.91	25.58	4.52
2001	Ibadan	Aug	83.80	97.72	76.97	21.89	27.02	24.45	1.43
2001	Ibadan	Sep	299.70	99.23	67.97	21.64	28.88	25.26	3.55
2001	Ibadan	Oct	52.40	98.98	64.84	22.22	31.12	26.67	6.21
2001	Ibadan	Nov	0.00	98.99	47.23	23.09	33.22	28.15	8.62
2001	Ibadan	Dec	0.00	99.00	46.28	23.51	33.85	28.68	8.16
2002	Ibadan	Jan	0.50	87.70	27.11	19.48	33.27	26.37	-9.00
2002	Ibadan	Feb	0.50	94.15	30.83	22.17	35.67	28.92	-9.00
2002	Ibadan	Mar	45.50	99.21	46.59	23.92	34.92	29.42	-9.00
2002	Ibadan	Apr	124.95	99.18	61.48	23.14	32.56	27.85	-9.00
2002	Ibadan	May	171.25	99.68	62.08	22.37	31.70	27.03	-9.00
2002	Ibadan	Jun	203.70	99.40	63.50	21.79	30.03	25.91	-9.00
2002	Ibadan	Jul	402.90	96.81	65.61	21.66	28.69	25.18	-9.00
2002	Ibadan	Aug	183.75	96.16	70.42	21.44	27.38	24.41	-9.00
2002	Ibadan	Sep	129.30	96.27	64.17	21.12	28.47	24.80	-9.00
2002	Ibadan	Oct	198.55	97.68	59.61	21.33	29.70	25.52	6.64
2002	Ibadan	Nov	34.50	95.03	42.97	22.52	31.78	27.15	8.24
2002	Ibadan	Dec	0.00	93.33	25.67	19.73	32.97	26.35	8.88

Appendix 4 Towards a conceptual modeling framework

Crop-livestock systems models should be able to do the following, at a minimum

1) Describe and quantify the interactions between the system's components.
2) Represent the farmer's management practices.
3) Determine the impacts of management strategies on use of land and other resources.
4) Quantify nutrient balances at the whole-system level.
5) Quantify the variability associated with different weather conditions on systems performance.
6) Provide insight into the trade-offs (economic, environmental and social) involved in using different farm resources.
7) Allow the possibility of studying both the medium- and the long-term effects of the strategies investigated.
8) Translate model outcomes into operational support for seasonal farm management.
9) Use minimum data sets for parameterization, validation and general use that can be assembled relatively easily.
10) Integrated data from different levels of aggregation.

Appendix 5 Total density of weed species identified across herbaceous legumes and management practices.

Obs	Sampling year	Location	Sampling time	REP	Herbaceous legumes (Main treatment)	Management practices (Sub-plot treatment)	Total density
1	2001	NGS	12MAP	1	Centro	*M1*	30.319
2	2001	NGS	12MAP	1	Centro	*M2*	44.365
3	2001	NGS	12MAP	1	Centro	*M3*	59.688
4	2001	NGS	12MAP	1	Cowpea	*M1*	33.054
5	2001	NGS	12MAP	1	Cowpea	*M2*	29.731
6	2001	NGS	12MAP	1	Cowpea	*M3*	41.47
7	2001	NGS	12MAP	1	Gnut	*M1*	41.49
8	2001	NGS	12MAP	1	Gnut	*M2*	49.126
9	2001	NGS	12MAP	1	Gnut	*M3*	44.806
10	2001	NGS	12MAP	1	Histrtix	*M1*	46.861
11	2001	NGS	12MAP	1	Histrtix	*M2*	56.953
12	2001	NGS	12MAP	1	Histrtix	*M3*	69.321
13	2001	NGS	12MAP	1	Soy	*M1*	26.883
14	2001	NGS	12MAP	1	Soy	*M2*	33.176
15	2001	NGS	12MAP	1	Soy	*M3*	30.15
16	2001	NGS	12MAP	1	Stylo	*M1*	22.889
17	2001	NGS	12MAP	1	Stylo	*M2*	27.685
18	2001	NGS	12MAP	1	Stylo	*M3*	41.346
19	2001	NGS	12MAP	1	Natural	*M1*	51.271
20	2001	NGS	12MAP	1	Natural	*M2*	43.199
21	2001	NGS	12MAP	1	Natural	*M3*	55.048
22	2001	NGS	12MAP	2	Centro	*M1*	57.667
23	2001	NGS	12MAP	2	Centro	*M2*	43.322
24	2001	NGS	12MAP	2	Centro	*M3*	58.068
25	2001	NGS	12MAP	2	Cowpea	*M1*	34.379
26	2001	NGS	12MAP	2	Cowpea	*M2*	32.972
27	2001	NGS	12MAP	2	Cowpea	*M3*	49.085
28	2001	NGS	12MAP	2	Gnut	*M1*	37.431
29	2001	NGS	12MAP	2	Gnut	*M2*	47.794
30	2001	NGS	12MAP	2	Gnut	*M3*	52.176
31	2001	NGS	12MAP	2	Histrtix	*M1*	55.962
32	2001	NGS	12MAP	2	Histrtix	*M2*	56.394
33	2001	NGS	12MAP	2	Histrtix	*M3*	48.057
34	2001	NGS	12MAP	2	Soy	*M1*	28.919
35	2001	NGS	12MAP	2	Soy	*M2*	54.883
36	2001	NGS	12MAP	2	Soy	*M3*	27.229
37	2001	NGS	12MAP	2	Stylo	*M1*	43.071
38	2001	NGS	12MAP	2	Stylo	*M2*	55.512
39	2001	NGS	12MAP	2	Stylo	*M3*	40.813

40	2001	NGS	12MAP	2	Natural	*M1*	53.277
41	2001	NGS	12MAP	2	Natural	*M2*	39.389
42	2001	NGS	12MAP	2	Natural	*M3*	51.536
43	2001	NGS	12MAP	3	Centro	*M1*	37.181
44	2001	NGS	12MAP	3	Centro	*M2*	36.889
45	2001	NGS	12MAP	3	Centro	*M3*	31.439
46	2001	NGS	12MAP	3	Cowpea	*M1*	20.083
47	2001	NGS	12MAP	3	Cowpea	*M2*	33.887
48	2001	NGS	12MAP	3	Cowpea	*M3*	39.594
49	2001	NGS	12MAP	3	Gnut	*M1*	22.118
50	2001	NGS	12MAP	3	Gnut	*M2*	30.073
51	2001	NGS	12MAP	3	Gnut	*M3*	31.101
52	2001	NGS	12MAP	3	Histrtix	*M1*	27.204
53	2001	NGS	12MAP	3	Histrtix	*M2*	29.178
54	2001	NGS	12MAP	3	Histrtix	*M3*	28.937
55	2001	NGS	12MAP	3	Soy	*M1*	19.114
56	2001	NGS	12MAP	3	Soy	*M2*	27.958
57	2001	NGS	12MAP	3	Soy	*M3*	24.941
58	2001	NGS	12MAP	3	Stylo	*M1*	29.722
59	2001	NGS	12MAP	3	Stylo	*M2*	27.765
60	2001	NGS	12MAP	3	Stylo	*M3*	22.625
61	2001	NGS	12MAP	3	Natural	*M1*	11.03
62	2001	NGS	12MAP	3	Natural	*M2*	43.311
63	2001	NGS	12MAP	3	Natural	*M3*	38.299
64	2001	NGS	12MAP	4	Centro	*M1*	29.868
65	2001	NGS	12MAP	4	Centro	*M2*	23.46
66	2001	NGS	12MAP	4	Centro	*M3*	27.64
67	2001	NGS	12MAP	4	Cowpea	*M1*	27.935
68	2001	NGS	12MAP	4	Cowpea	*M2*	27.036
69	2001	NGS	12MAP	4	Cowpea	*M3*	29.767
70	2001	NGS	12MAP	4	Gnut	*M1*	22.242
71	2001	NGS	12MAP	4	Gnut	*M2*	29.42
72	2001	NGS	12MAP	4	Gnut	*M3*	33.083
73	2001	NGS	12MAP	4	Histrtix	*M1*	38.853
74	2001	NGS	12MAP	4	Histrtix	*M2*	34.82
75	2001	NGS	12MAP	4	Histrtix	*M3*	21.15
76	2001	NGS	12MAP	4	Soy	*M1*	24.078
77	2001	NGS	12MAP	4	Soy	*M2*	21.481
78	2001	NGS	12MAP	4	Soy	*M3*	30.769
79	2001	NGS	12MAP	4	Stylo	*M1*	30.886
80	2001	NGS	12MAP	4	Stylo	*M2*	21.513
81	2001	NGS	12MAP	4	Stylo	*M3*	20.444
82	2001	NGS	12MAP	4	Natural	*M1*	28.837
83	2001	NGS	12MAP	4	Natural	*M2*	30.534
84	2001	NGS	12MAP	4	Natural	*M3*	18.725

85	2001	NGS	15MAP	1	Centro	*M1*	62.33
86	2001	NGS	15MAP	1	Centro	*M2*	54.885
87	2001	NGS	15MAP	1	Centro	*M3*	61.712
88	2001	NGS	15MAP	1	Cowpea	*M1*	23.61
89	2001	NGS	15MAP	1	Cowpea	*M2*	69.19
90	2001	NGS	15MAP	1	Cowpea	*M3*	41.393
91	2001	NGS	15MAP	1	Gnut	*M1*	49.603
92	2001	NGS	15MAP	1	Gnut	*M2*	50.934
93	2001	NGS	15MAP	1	Gnut	*M3*	51.271
94	2001	NGS	15MAP	1	Histrtix	*M1*	51.539
95	2001	NGS	15MAP	1	Histrtix	*M2*	62.618
96	2001	NGS	15MAP	1	Histrtix	*M3*	71.452
97	2001	NGS	15MAP	1	Soy	*M1*	26.186
98	2001	NGS	15MAP	1	Soy	*M2*	35.329
99	2001	NGS	15MAP	1	Soy	*M3*	32.253
100	2001	NGS	15MAP	1	Stylo	*M1*	151.502
101	2001	NGS	15MAP	1	Stylo	*M2*	51.061
102	2001	NGS	15MAP	1	Natural	*M1*	72.309
103	2001	NGS	15MAP	1	Natural	*M2*	76.026
104	2001	NGS	15MAP	1	Natural	*M3*	78.831
105	2001	NGS	15MAP	2	Centro	*M1*	28.456
106	2001	NGS	15MAP	2	Centro	*M2*	50.009
107	2001	NGS	15MAP	2	Centro	*M3*	52.474
108	2001	NGS	15MAP	2	Cowpea	*M1*	42.689
109	2001	NGS	15MAP	2	Cowpea	*M2*	52.914
110	2001	NGS	15MAP	2	Cowpea	*M3*	38.502
111	2001	NGS	15MAP	2	Gnut	*M1*	46.863
112	2001	NGS	15MAP	2	Gnut	*M2*	51.205
113	2001	NGS	15MAP	2	Gnut	*M3*	44.058
114	2001	NGS	15MAP	2	Histrtix	*M1*	41.594
115	2001	NGS	15MAP	2	Histrtix	*M2*	65.382
116	2001	NGS	15MAP	2	Histrtix	*M3*	64.195
117	2001	NGS	15MAP	2	Soy	*M1*	24.814
118	2001	NGS	15MAP	2	Soy	*M2*	45.5
119	2001	NGS	15MAP	2	Soy	*M3*	28.229
120	2001	NGS	15MAP	2	Stylo	*M1*	55.818
121	2001	NGS	15MAP	2	Stylo	*M2*	60.511
122	2001	NGS	15MAP	2	Stylo	*M3*	64.904
123	2001	NGS	15MAP	2	Natural	*M1*	36.892
124	2001	NGS	15MAP	2	Natural	*M2*	41.463
125	2001	NGS	15MAP	2	Natural	*M3*	48.583
126	2001	NGS	15MAP	3	Centro	*M1*	29.103
127	2001	NGS	15MAP	3	Centro	*M2*	45.386
128	2001	NGS	15MAP	3	Centro	*M3*	50.704
129	2001	NGS	15MAP	3	Cowpea	*M1*	33.523

130	2001	NGS	15MAP	3	Cowpea	*M2*	39.003
131	2001	NGS	15MAP	3	Cowpea	*M3*	45.949
132	2001	NGS	15MAP	3	Gnut	*M1*	55.467
133	2001	NGS	15MAP	3	Gnut	*M2*	70.359
134	2001	NGS	15MAP	3	Gnut	*M3*	41.223
135	2001	NGS	15MAP	3	Histrtix	*M1*	61.726
136	2001	NGS	15MAP	3	Histrtix	*M2*	49.504
137	2001	NGS	15MAP	3	Histrtix	*M3*	56.197
138	2001	NGS	15MAP	3	Soy	*M1*	51.498
139	2001	NGS	15MAP	3	Soy	*M2*	29.281
140	2001	NGS	15MAP	3	Soy	*M3*	46.087
141	2001	NGS	15MAP	3	Stylo	*M1*	49.278
142	2001	NGS	15MAP	3	Stylo	*M2*	28.001
143	2001	NGS	15MAP	3	Stylo	*M3*	46.632
144	2001	NGS	15MAP	3	Natural	*M1*	19.786
145	2001	NGS	15MAP	3	Natural	*M2*	36.13
146	2001	NGS	15MAP	3	Natural	*M3*	41.736
147	2001	NGS	15MAP	4	Centro	*M1*	23.455
148	2001	NGS	15MAP	4	Centro	*M2*	49.92
149	2001	NGS	15MAP	4	Centro	*M3*	54.549
150	2001	NGS	15MAP	4	Cowpea	*M1*	22.165
151	2001	NGS	15MAP	4	Cowpea	*M2*	17.92
152	2001	NGS	15MAP	4	Cowpea	*M3*	34.953
153	2001	NGS	15MAP	4	Gnut	*M1*	43.325
154	2001	NGS	15MAP	4	Gnut	*M2*	33.104
155	2001	NGS	15MAP	4	Gnut	*M3*	43.52
156	2001	NGS	15MAP	4	Histrtix	*M1*	45.732
157	2001	NGS	15MAP	4	Histrtix	*M2*	60.961
158	2001	NGS	15MAP	4	Histrtix	*M3*	46.866
159	2001	NGS	15MAP	4	Soy	*M1*	18.943
160	2001	NGS	15MAP	4	Soy	*M3*	44.76
161	2001	NGS	15MAP	4	Stylo	*M1*	21.4
162	2001	NGS	15MAP	4	Stylo	*M2*	26.419
163	2001	NGS	15MAP	4	Stylo	*M3*	41.502
164	2001	NGS	15MAP	4	Natural	*M1*	33.717
165	2001	NGS	15MAP	4	Natural	*M2*	28.699
166	2001	NGS	15MAP	4	Natural	*M3*	50.336

Appendix 6 Size of experimental Unit:

Assuming the feeding period is for 4 days during the late dry season, after *in situ* weeds and residues have been exhausted (this is in line with the farmers' practice of allowing animals to roam for the first part of the dry season, then confining them for the latter), the TLU that can be fed from the forage harvested from each treatment is calculated on the basis of 7.5 kg dry matter per TLU per day[7] as:

Let the total harvest for a plot be H kg (this is legume plus weeds, or natural fallow):

1 TLU of 250kg needs (250 * (3/100)) kg DM per day = 7.5kg day^{-1}

Approx. 7.5kg DM per day

For 4 days, 4 * 7.5 = 30 kg DM for 1 TLU

If we have H kg of feed from a plot then

H/30 = T_{no}. of TLU that can be fed for 4 days

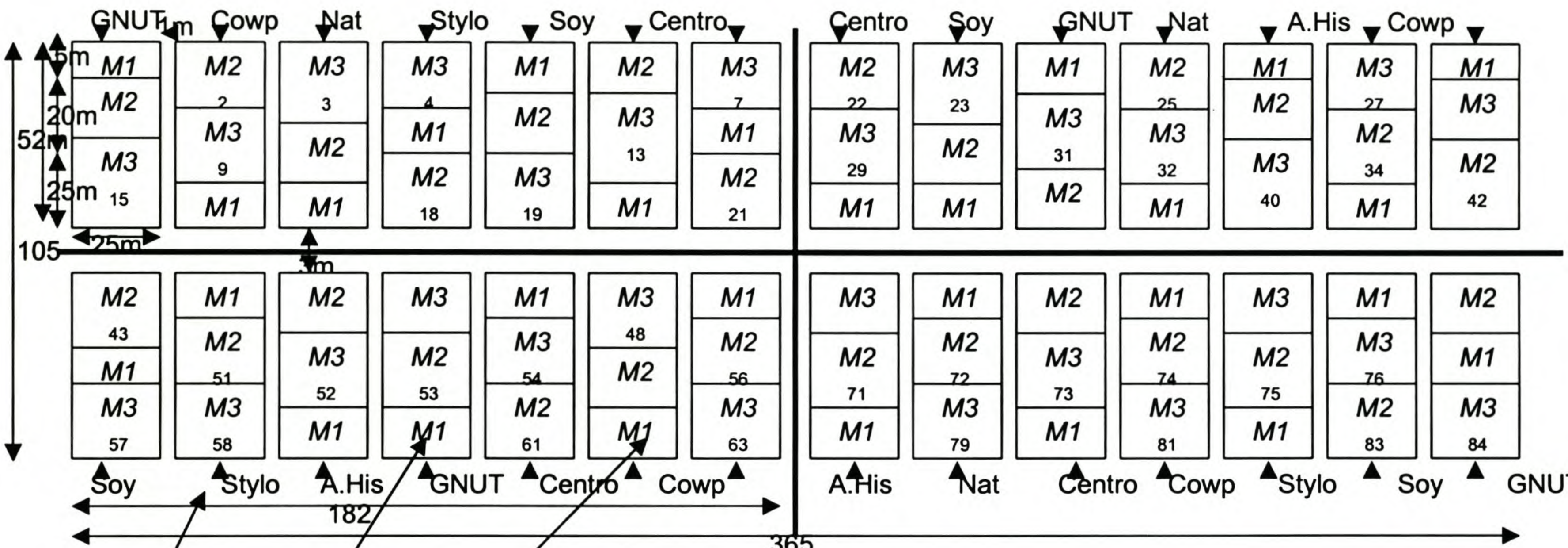
T_{no}. * 250 = kg of LW per day that can be fed for 4 days.

The approx. LW of the sheep for this experiment is between 30-35 kg. approx.

1000g=1kg DM feeds Considering a situation where we give approx. 2kg Dm per day then,

[7]TLU – Tropical Livestock Unit, 250 kg liveweight for cattle. Usual recommendation is that feed requirement would be 3% of body weight day^{-1}, this would mean 7.5kg dry matter per day.

1st year field layout



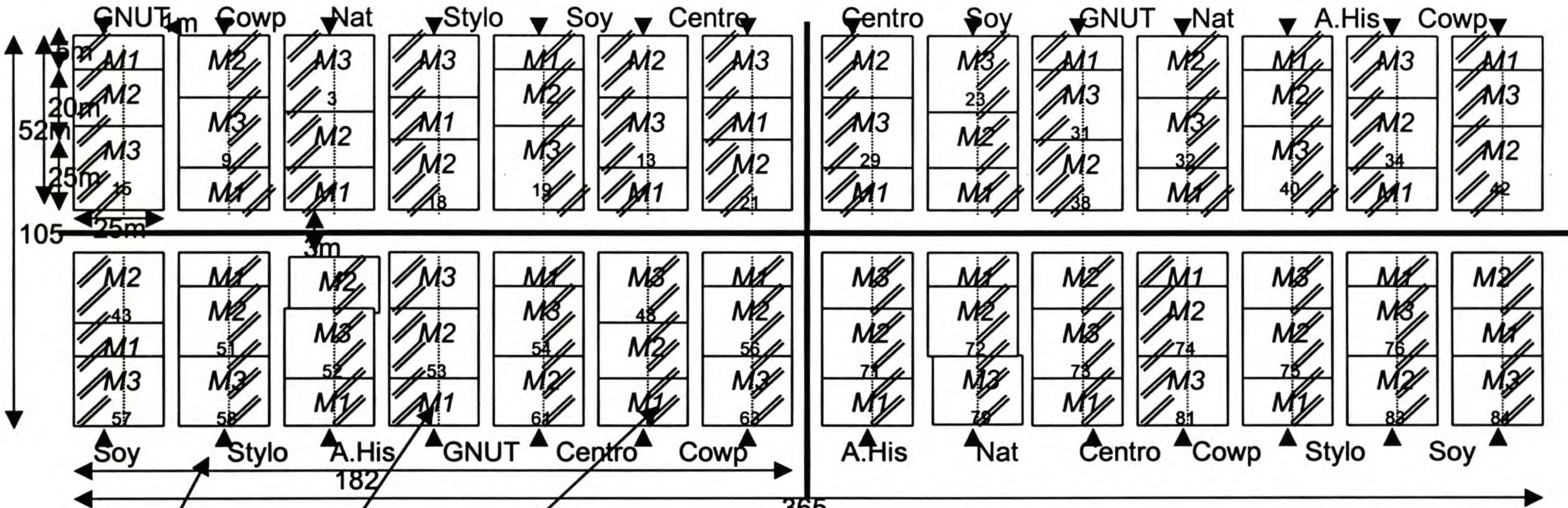
Appendix 7 Plot layout in Zaria, 2000

Sub Plot ID and size

M1 →Legume fallow =→5m x 25m→125*M2*
M2 →Legume+cut/carry =→20m x 25m→500*M2*
M3 →Legume+cut/carry+Manure/Urine returned =→25m x 25m→625*M2*

Rep→4; Area per rep→ 8750*M2*; Main plot area→25 by 50 =1250*M2*; Total exp.

2nd year field layout, showing the splitting of treatments



Main Plot

Sub Plot

Plot No.

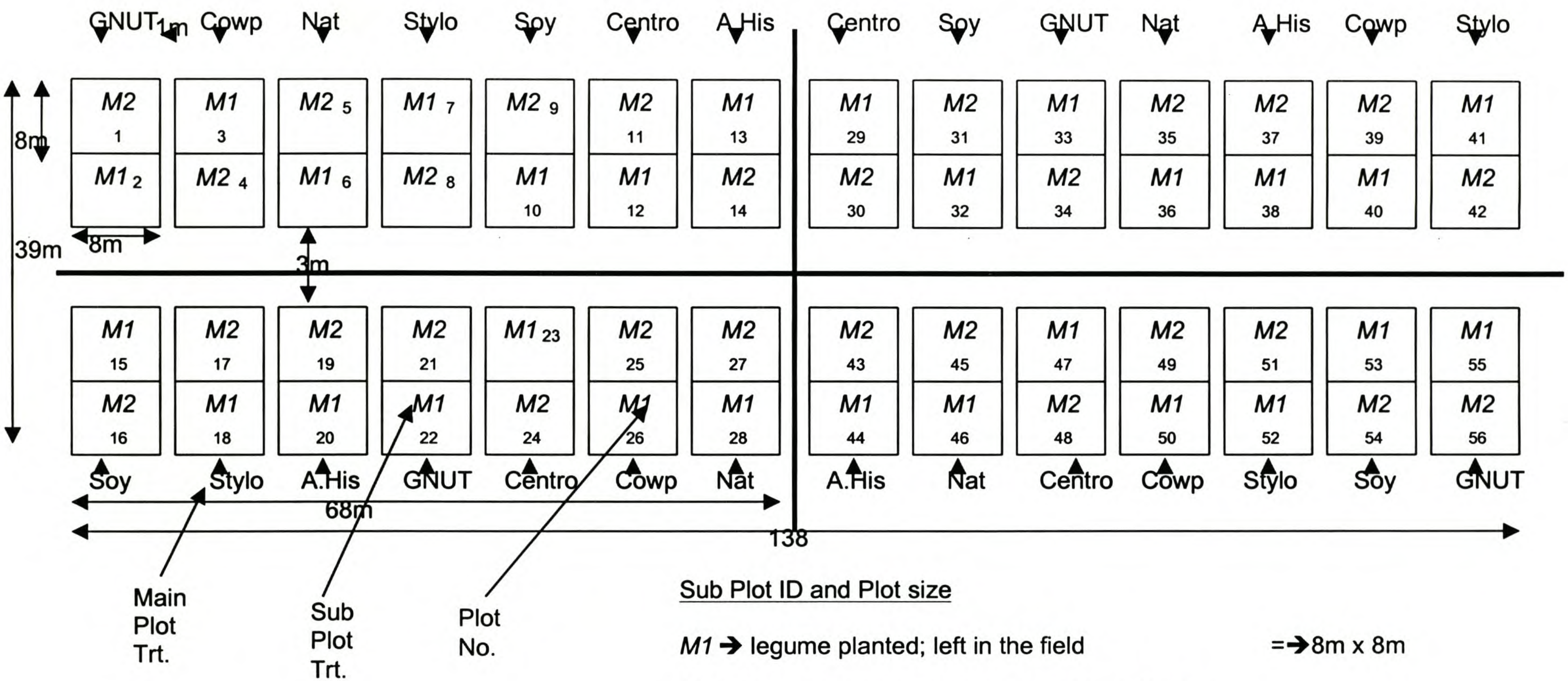
FALLOW	MAIZE	MAIZE
FALLOW	FALLOW	MAIZE

<u>Sub Plot ID and size</u>

M1 →Legume fallow =→5m x 25m→125*M2*
M2 →Legume+cut/carry =→20m x 25m→500*M2*
M3 →Legume+cut/carry+Manure/Urine returned =→25m x 25m→625*M2*

Appendix 8 Plot layout in Zaria, 2001

FIELD LAYOUT



<u>Sub Plot ID and Plot size</u>

M1 ➔ legume planted; left in the field =➔8m x 8m

M2 ➔ legume planted, harvested taken out of the field for livestock feed =➔8m x 8m

Reps = 4

Appendix 9 Plot layout for smaller plot in Zaria and Ibadan, 2001-2002

ppendix 10 Forage produced and TLU of livestock available at NAPRI, 2002 dry season (all amounts in kg).

Syear	Sside	Sampl	Mplot	Splot	cropStov	Cob	Grain	HLbio	WeedMZ	soilpH	soilOC	soilN	soilCN	soilP	ECEC	Compost	LvP	LvN	LvOM
2001	1yrF1yrM	1	Centro	*M1*	1.03	1.48	0.67	1.01	22.34	5.00	1.26	0.09	14.82	5.20	4.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Centro	*M1*	1.86	2.62	1.21	2.83	11.47	5.70	0.78	0.09	8.48	17.40	6.10	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Centro	*M1*	0.71	0.67	0.06	3.77	19.59	5.10	0.61	0.08	7.35	4.00	4.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Centro	*M1*	0.61	0.48	0.00	1.74	10.70	5.40	0.88	0.08	11.58	9.00	4.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Cowpea	*M1*	1.19	1.16	0.51	0.51	7.38	4.90	0.63	0.10	6.56	6.60	4.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Cowpea	*M1*	2.32	1.87	1.11	0.39	28.75	5.30	0.59	0.08	7.20	6.30	4.60	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Cowpea	*M1*	0.68	0.60	0.07	2.17	11.98	5.30	0.66	0.06	11.00	9.40	4.90	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Cowpea	*M1*	1.25	0.95	0.31	0.65	9.07	5.00	0.55	0.08	7.05	5.60	6.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Gnut	*M1*	1.59	1.92	0.62	6.27	10.36	5.10	0.91	0.09	10.34	8.30	5.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Gnut	*M1*	3.74	3.84	1.54	2.90	14.20	5.50	0.74	0.11	6.85	10.60	5.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Gnut	*M1*	0.24	1.48	0.31	6.23	13.75	5.30	0.72	0.07	11.08	0.80	4.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Gnut	*M1*	0.79	0.44	0.01	4.64	14.92	5.10	0.40	0.08	5.33	4.80	4.10	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Histrix	*M1*	1.42	1.39	0.72	0.58	11.82	5.00	1.00	0.09	10.75	6.00	2.80	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Histrix	*M1*	3.32	3.95	2.51	0.72	13.68	5.40	0.47	0.11	4.35	8.40	6.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Histrix	*M1*	1.01	1.66	0.34	0.36	9.17	5.00	0.76	0.11	7.10	2.30	5.00	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Histrix	*M1*	1.09	0.56	0.04	2.25	23.72	4.90	0.66	0.09	7.67	9.60	4.00	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Natural	*M1*	1.09	1.51	0.73	0.35	22.05	5.00	1.02	0.10	10.52	5.00	3.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Natural	*M1*	4.30	2.58	1.35	0.57	12.07	5.40	1.02	0.12	8.29	5.50	9.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Natural	*M1*	0.94	0.67	0.08	0.35	10.13	5.30	1.01	0.06	18.04	12.40	5.60	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Natural	*M1*	0.80	0.60	0.14	0.57	8.03	5.20	0.61	0.06	9.68	2.80	3.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Soy	*M1*	1.17	1.79	0.84	5.07	17.45	5.20	0.72	0.08	8.78	3.60	4.60	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Soy	*M1*	5.01	3.51	2.13	8.12	22.88	5.20	0.74	0.12	6.12	16.50	6.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Soy	*M1*	0.91	0.93	0.16	2.03	14.81	5.50	0.67	0.06	11.36	4.40	4.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Soy	*M1*	0.81	0.92	0.22	1.23	17.45	5.00	0.60	0.06	9.52	4.10	3.00	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Stylo	*M1*	2.32	2.18	1.15	3.48	23.10	5.20	0.69	0.12	6.00	7.50	6.10	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Stylo	*M1*	2.48	2.15	1.15	2.32	16.94	5.30	1.07	0.12	9.22	22.30	7.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Stylo	*M1*	2.18	1.39	1.15	1.59	18.04	5.40	0.85	0.06	14.17	8.60	6.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Stylo	*M1*	1.84	0.60	0.22	2.90	16.16	5.30	0.63	0.08	8.29	10.90	8.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Centro	*M2*	2.58	1.72	0.85	2.00	21.68	4.90	0.80	0.09	9.30	4.10	4.80	0.00	0.00	0.00	0.00

2001	1yrF1yrM	2	Centro	*M2*	2.03	2.92	1.46	1.15	18.17	5.30	0.86	0.08	11.03	4.10	3.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Centro	*M2*	3.30	1.31	0.37	2.11	16.71	5.20	0.51	0.08	6.46	10.00	3.60	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Centro	*M2*	0.58	0.67	0.14	0.68	10.95	5.00	0.70	0.07	9.46	4.40	3.40	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Cowpea	*M2*	3.32	3.63	1.97	0.42	7.57	5.00	1.18	0.08	15.32	8.80	3.90	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Cowpea	*M2*	1.59	1.83	1.06	0.52	18.03	5.60	0.77	0.12	6.70	11.00	8.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Cowpea	*M2*	1.23	0.98	0.23	0.40	9.33	5.30	0.61	0.06	9.84	8.00	4.90	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Cowpea	*M2*	0.72	0.89	0.39	0.53	12.21	5.20	0.51	0.05	9.81	2.80	2.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Gnut	*M2*	3.17	3.87	1.77	4.19	9.75	5.20	0.91	0.11	8.35	20.00	6.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Gnut	*M2*	1.98	2.47	1.54	2.16	17.11	5.50	0.68	0.08	8.72	7.50	4.10	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Gnut	*M2*	0.67	0.93	0.18	2.00	15.36	5.20	0.74	0.07	10.00	3.50	3.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Gnut	*M2*	0.76	0.34	0.01	2.43	10.23	5.30	0.97	0.08	12.60	5.40	4.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Histrtix	*M2*	1.61	1.35	0.66	0.27	17.56	5.20	1.06	0.09	11.65	5.20	5.90	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Histrtix	*M2*	2.23	2.41	1.34	0.34	15.01	5.20	1.02	0.09	11.21	11.50	4.20	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Histrtix	*M2*	1.02	1.13	0.29	0.35	14.96	5.20	0.92	0.07	12.60	2.50	4.60	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Histrtix	*M2*	0.79	0.49	0.02	0.29	24.65	5.00	0.46	0.07	6.48	3.60	2.70	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Natural	*M2*	1.62	1.69	1.04	0.32	22.01	5.40	1.12	0.08	14.55	2.50	4.00	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Natural	*M2*	2.67	1.98	0.81	0.35	7.05	5.50	0.61	0.10	6.35	4.40	6.60	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Natural	*M2*	2.03	2.72	1.08	0.28	8.87	5.50	0.89	0.06	15.34	7.70	4.80	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Natural	*M2*	0.90	0.95	0.27	0.29	12.33	5.00	0.78	0.06	12.19	3.90	4.40	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Soy	*M2*	1.72	1.92	0.96	3.39	16.18	5.10	1.03	0.11	9.63	6.90	6.80	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Soy	*M2*	3.79	4.16	2.28	4.02	27.69	5.30	0.78	0.11	7.16	12.90	5.40	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Soy	*M2*	1.07	1.16	0.22	1.96	13.61	5.50	0.56	0.08	7.00	10.90	6.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Soy	*M2*	1.08	0.47	0.01	1.28	13.79	5.30	0.96	0.06	16.55	4.80	3.40	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Stylo	*M2*	2.80	8.66	1.27	4.30	16.56	4.80	0.85	0.10	8.76	6.00	4.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	2	Stylo	*M2*	4.06	2.99	1.86	1.67	12.07	5.20	0.64	0.13	4.89	7.30	5.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	3	Stylo	*M2*	1.30	0.64	1.86	1.15	8.78	5.60	1.04	0.06	17.05	6.40	3.30	0.00	0.00	0.00	0.00
2001	1yrF1yrM	4	Stylo	*M2*	1.00	1.01	0.42	1.86	18.34	5.10	0.58	0.06	9.35	6.40	2.50	0.00	0.00	0.00	0.00
2001	1yrF1yrM	1	Centro	*M3*	2.39	2.25	1.22	1.11	13.32	5.70	1.34	0.12	10.81	6.20	7.50	0.37	0.58	2.38	89.47
2001	1yrF1yrM	2	Centro	*M3*	2.71	2.50	1.83	1.93	24.42	5.50	0.90	0.07	13.43	4.40	6.80	0.39	0.41	2.50	87.79
2001	1yrF1yrM	3	Centro	*M3*	1.45	0.72	0.11	1.68	9.69	5.20	1.14	0.09	13.41	12.10	3.80	0.46	0.35	1.48	89.90
2001	1yrF1yrM	4	Centro	*M3*	0.69	0.68	0.13	0.92	12.41	5.50	1.15	0.05	21.70	3.70	5.70	0.66	0.42	1.67	89.00
2001	1yrF1yrM	1	Cowpea	*M3*	4.02	4.01	2.13	0.61	11.25	5.00	1.08	0.08	13.50	4.20	4.50	0.26	0.22	2.09	90.43

2001	1yrF1yrM	2	Cowpea	*M3*	2.05	1.90	0.86	0.58	19.45	5.20	0.63	0.07	9.69	7.30	3.40	0.40	0.45	2.31	89.92
2001	1yrF1yrM	3	Cowpea	*M3*	1.53	1.77	0.63	0.63	15.08	5.40	1.58	0.06	25.08	4.60	4.30	0.26	0.28	1.51	89.21
2001	1yrF1yrM	4	Cowpea	*M3*	1.21	0.46	0.03	0.64	12.05	5.20	0.65	0.07	9.03	11.00	4.90	0.21	0.17	1.49	92.41
2001	1yrF1yrM	1	Gnut	*M3*	5.09	4.55	2.72	3.39	13.77	5.40	0.73	0.13	5.75	5.40	6.90	0.44	0.38	2.08	81.73
2001	1yrF1yrM	2	Gnut	*M3*	4.31	3.97	2.17	1.85	14.03	5.90	0.98	0.10	10.00	7.70	5.60	0.82	0.27	2.15	86.34
2001	1yrF1yrM	3	Gnut	*M3*	0.57	0.95	0.22	1.59	15.17	5.30	0.94	0.10	9.59	4.20	4.20	0.39	0.40	1.82	84.47
2001	1yrF1yrM	4	Gnut	*M3*	0.97	0.46	0.00	2.45	12.37	5.00	0.86	0.07	12.65	5.10	6.10	0.58	0.59	2.68	82.67
2001	1yrF1yrM	1	Histrtix	*M3*	1.25	1.23	0.44	0.26	12.53	5.20	0.97	0.07	13.11	5.90	3.00	0.14	0.50	2.01	89.26
2001	1yrF1yrM	2	Histrtix	*M3*	1.90	2.51	1.42	0.51	20.34	5.30	0.97	0.09	10.43	9.10	7.10	0.14	0.40	1.80	90.20
2001	1yrF1yrM	3	Histrtix	*M3*	1.40	1.58	0.47	0.25	6.71	5.30	1.00	0.07	14.93	2.20	3.40	0.11	0.28	1.45	84.36
2001	1yrF1yrM	4	Histrtix	*M3*	1.35	0.61	0.10	0.43	13.25	4.90	1.02	0.12	8.50	3.60	4.10	0.11	0.51	2.28	90.78
2001	1yrF1yrM	1	Natural	*M3*	2.09	1.87	0.89	0.35	15.61	4.80	0.55	0.10	5.29	5.20	5.80	0.39	0.28	1.28	87.26
2001	1yrF1yrM	2	Natural	*M3*	4.25	2.23	1.20	0.46	10.92	5.30	1.19	0.10	11.55	5.80	6.20	0.40	0.54	2.10	85.97
2001	1yrF1yrM	3	Natural	*M3*	1.28	1.08	0.28	0.43	8.53	5.30	0.62	0.05	11.92	2.70	3.40	0.30	0.49	1.80	88.77
2001	1yrF1yrM	4	Natural	*M3*	0.89	0.65	0.06	0.64	11.05	5.70	0.82	0.13	6.41	10.10	6.60	0.36	0.42	1.72	89.92
2001	1yrF1yrM	1	Soy	*M3*	2.39	2.70	1.48	3.82	15.69	4.90	0.75	0.09	8.62	5.20	3.80	1.30	0.32	1.88	91.78
2001	1yrF1yrM	2	Soy	*M3*	2.55	2.83	1.55	4.06	19.07	5.20	0.66	0.10	6.60	3.30	4.00	1.61	0.31	1.44	80.67
2001	1yrF1yrM	3	Soy	*M3*	0.91	1.64	0.42	2.29	13.05	5.30	0.69	0.06	12.11	7.30	3.80	1.02	0.24	1.38	93.00
2001	1yrF1yrM	4	Soy	*M3*	1.09	0.61	0.10	1.54	11.16	5.40	1.01	0.08	13.12	13.80	5.40	0.82	0.29	1.39	94.44
2001	1yrF1yrM	1	Stylo	*M3*	2.19	2.37	1.33	1.61	23.01	5.00	1.12	0.12	9.57	17.30	5.60	0.79	0.25	1.34	93.48
2001	1yrF1yrM	2	Stylo	*M3*	3.30	3.12	2.24	1.64	22.74	6.00	0.68	0.11	6.36	4.90	8.70	1.09	0.32	1.63	90.90
2001	1yrF1yrM	3	Stylo	*M3*	1.00	1.90	2.24	0.61	13.82	5.20	0.71	0.06	11.64	2.10	3.30	0.33	0.28	1.64	92.91
2001	1yrF1yrM	4	Stylo	*M3*	0.80	1.43	0.53	1.47	22.74	5.20	1.01	0.06	16.56	4.30	3.90	0.30	0.37	1.66	88.46
2002	1yrF2yrM	1	Centro	*M1*	4.65	2.28	1.84	3.17	11.16	5.00	1.26	0.09	14.82	5.20	4.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Centro	*M1*	8.68	3.27	2.71	6.00	16.06	5.70	0.78	0.09	8.48	17.40	6.10	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Centro	*M1*	1.92	0.79	0.61	4.00	25.39	5.10	0.61	0.08	7.35	4.00	4.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Centro	*M1*	2.52	0.70	0.53	9.33	33.59	5.40	0.88	0.08	11.58	9.00	4.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Cowpea	*M1*	4.31	3.18	2.62	1.32	25.98	4.90	0.63	0.10	6.56	6.60	4.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Cowpea	*M1*	5.95	3.47	2.84	2.04	14.84	5.30	0.59	0.08	7.20	6.30	4.60	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Cowpea	*M1*	4.14	0.59	0.46	1.08	27.09	5.30	0.66	0.06	11.00	9.40	4.90	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Cowpea	*M1*	4.10	1.62	1.28	1.11	22.07	5.00	0.55	0.08	7.05	5.60	6.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Gnut	*M1*	2.79	2.22	1.74	3.91	14.57	5.10	0.91	0.09	10.34	8.30	5.50	0.00	0.00	0.00	0.00

2002	1yrF2yrM	2	Gnut	*M1*	7.64	4.21	3.48	1.68	16.26	5.50	0.74	0.11	6.85	10.60	5.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Gnut	*M1*	3.43	1.15	0.87	2.58	21.66	5.30	0.72	0.07	11.08	0.80	4.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Gnut	*M1*	2.79	1.41	1.13	3.27	30.35	5.10	0.40	0.08	5.33	4.80	4.10	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Histrtix	*M1*	5.14	3.28	2.66	3.53	22.25	5.00	1.00	0.09	10.75	6.00	2.80	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Histrtix	*M1*	6.87	2.64	2.15	7.40	16.87	5.40	0.47	0.11	4.35	8.40	6.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Histrtix	*M1*	2.62	1.06	0.81	3.27	23.13	5.00	0.76	0.11	7.10	2.30	5.00	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Histrtix	*M1*	4.05	2.22	1.77	4.67	44.25	4.90	0.66	0.09	7.67	9.60	4.00	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Natural	*M1*	6.27	3.81	3.09	3.17	15.41	5.00	1.02	0.10	10.52	5.00	3.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Natural	*M1*	5.35	2.22	1.79	6.33	23.94	5.40	1.02	0.12	8.29	5.50	9.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Natural	*M1*	3.54	1.08	0.85	5.83	20.43	5.30	1.01	0.06	18.04	12.40	5.60	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Natural	*M1*	4.39	1.69	1.34	8.00	14.99	5.20	0.61	0.06	9.68	2.80	3.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Soy	*M1*	11.82	3.22	2.63	0.33	25.54	5.20	0.72	0.08	8.78	3.60	4.60	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Soy	*M1*	9.51	5.81	4.71	0.35	19.66	5.20	0.74	0.12	6.12	16.50	6.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Soy	*M1*	6.69	2.40	1.89	0.49	29.11	5.50	0.67	0.06	11.36	4.40	4.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Soy	*M1*	2.07	1.08	0.87	0.58	52.55	5.00	0.60	0.06	9.52	4.10	3.00	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Stylo	*M1*	3.35	2.29	1.82	4.33	14.42	5.20	0.69	0.12	6.00	7.50	6.10	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Stylo	*M1*	4.50	1.76	1.42	17.30	30.22	5.30	1.07	0.12	9.22	22.30	7.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Stylo	*M1*	4.18	2.68	2.17	7.47	34.81	5.40	0.85	0.06	14.17	8.60	6.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Stylo	*M1*	4.99	1.96	1.58	9.17	48.32	5.30	0.63	0.08	8.29	10.90	8.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Centro	*M2*	4.74	2.67	2.17	5.33	12.32	4.90	0.80	0.09	9.30	4.10	4.80	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Centro	*M2*	5.31	3.51	2.93	6.53	37.31	5.30	0.86	0.08	11.03	4.10	3.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Centro	*M2*	2.88	1.19	0.94	5.10	23.74	5.20	0.51	0.08	6.46	10.00	3.60	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Centro	*M2*	3.41	1.29	1.01	9.17	26.65	5.00	0.70	0.07	9.46	4.40	3.40	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Cowpea	*M2*	3.93	2.63	2.10	1.65	21.23	5.00	1.18	0.08	15.32	8.80	3.90	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Cowpea	*M2*	4.35	1.86	1.50	2.04	12.44	5.60	0.77	0.12	6.70	11.00	8.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Cowpea	*M2*	1.54	1.26	1.00	1.36	47.69	5.30	0.61	0.06	9.84	8.00	4.90	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Cowpea	*M2*	3.16	0.75	0.59	1.01	24.74	5.20	0.51	0.05	9.81	2.80	2.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Gnut	*M2*	3.67	3.01	2.44	6.31	11.56	5.20	0.91	0.11	8.35	20.00	6.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Gnut	*M2*	5.21	2.39	1.99	3.75	20.95	5.50	0.68	0.08	8.72	7.50	4.10	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Gnut	*M2*	2.33	0.69	0.50	4.25	35.42	5.20	0.74	0.07	10.00	3.50	3.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Gnut	*M2*	3.05	1.31	1.04	3.55	22.45	5.30	0.97	0.08	12.60	5.40	4.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Histrtix	*M2*	5.16	3.73	3.00	4.83	24.07	5.20	1.06	0.09	11.65	5.20	5.90	0.00	0.00	0.00	0.00

2002	1yrF2yrM	2	Histrtix	*M2*	6.31	3.90	3.21	6.80	24.40	5.20	1.02	0.09	11.21	11.50	4.20	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Histrtix	*M2*	3.11	0.77	0.55	5.87	21.98	5.20	0.92	0.07	12.60	2.50	4.60	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Histrtix	*M2*	3.16	1.49	1.19	8.77	37.38	5.00	0.46	0.07	6.48	3.60	2.70	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Natural	*M2*	6.19	4.42	3.56	5.17	19.15	5.40	1.12	0.08	14.55	2.50	4.00	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Natural	*M2*	4.95	1.17	0.94	4.50	20.09	5.50	0.61	0.10	6.35	4.40	6.60	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Natural	*M2*	4.16	1.71	1.32	5.33	39.88	5.50	0.89	0.06	15.34	7.70	4.80	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Natural	*M2*	3.88	0.69	0.52	8.00	39.36	5.00	0.78	0.06	12.19	3.90	4.40	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Soy	*M2*	7.08	3.80	3.08	0.37	22.17	5.10	1.03	0.11	9.63	6.90	6.80	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Soy	*M2*	7.25	4.04	3.30	0.69	12.40	5.30	0.78	0.11	7.16	12.90	5.40	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Soy	*M2*	7.62	3.37	2.75	0.49	23.72	5.50	0.56	0.08	7.00	10.90	6.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Soy	*M2*	2.54	0.81	0.63	0.46	32.34	5.30	0.96	0.06	16.55	4.80	3.40	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Stylo	*M2*	3.86	2.05	1.55	9.00	14.66	4.80	0.85	0.10	8.76	6.00	4.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	2	Stylo	*M2*	6.31	1.67	1.35	17.17	14.10	5.20	0.64	0.13	4.89	7.30	5.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	3	Stylo	*M2*	2.39	1.43	1.14	5.67	17.39	5.60	1.04	0.06	17.05	6.40	3.30	0.00	0.00	0.00	0.00
2002	1yrF2yrM	4	Stylo	*M2*	2.62	0.89	0.69	7.50	34.41	5.10	0.58	0.06	9.35	6.40	2.50	0.00	0.00	0.00	0.00
2002	1yrF2yrM	1	Centro	*M3*	5.14	3.02	2.38	4.17	12.83	5.70	1.34	0.12	10.81	6.20	7.50	2.83	0.58	2.38	89.47
2002	1yrF2yrM	2	Centro	*M3*	7.34	3.87	3.25	6.23	41.66	5.50	0.90	0.07	13.43	4.40	6.80	2.67	0.41	2.50	87.79
2002	1yrF2yrM	3	Centro	*M3*	2.07	1.36	1.06	2.50	29.33	5.20	1.14	0.09	13.41	12.10	3.80	7.35	0.35	1.48	89.90
2002	1yrF2yrM	4	Centro	*M3*	2.77	0.82	0.63	5.40	37.75	5.50	1.15	0.05	21.70	3.70	5.70	6.35	0.42	1.67	89.00
2002	1yrF2yrM	1	Cowpea	*M3*	2.56	2.37	1.87	2.13	22.83	5.00	1.08	0.08	13.50	4.20	4.50	2.58	0.22	2.09	90.43
2002	1yrF2yrM	2	Cowpea	*M3*	5.50	2.32	1.91	0.85	11.28	5.20	0.63	0.07	9.69	7.30	3.40	1.37	0.45	2.31	89.92
2002	1yrF2yrM	3	Cowpea	*M3*	3.03	2.48	1.96	0.74	35.74	5.40	1.58	0.06	25.08	4.60	4.30	1.22	0.28	1.51	89.21
2002	1yrF2yrM	4	Cowpea	*M3*	3.95	1.60	1.27	1.20	29.33	5.20	0.65	0.07	9.03	11.00	4.90	1.33	0.17	1.49	92.41
2002	1yrF2yrM	1	Gnut	*M3*	5.59	3.55	2.84	5.93	24.85	5.40	0.73	0.13	5.75	5.40	6.90	6.08	0.38	2.08	81.73
2002	1yrF2yrM	2	Gnut	*M3*	4.10	2.29	1.85	3.96	10.56	5.90	0.98	0.10	10.00	7.70	5.60	2.32	0.27	2.15	86.34
2002	1yrF2yrM	3	Gnut	*M3*	4.42	2.56	2.08	3.30	601.14	5.30	0.94	0.10	9.59	4.20	4.20	2.32	0.40	1.82	84.47
2002	1yrF2yrM	4	Gnut	*M3*	1.64	0.68	0.50	3.75	29.18	5.00	0.86	0.07	12.65	5.10	6.10	2.25	0.59	2.68	82.67
2002	1yrF2yrM	1	Histrtix	*M3*	5.95	3.23	2.63	2.67	25.93	5.20	0.97	0.07	13.11	5.90	3.00	3.50	0.50	2.01	89.26
2002	1yrF2yrM	2	Histrtix	*M3*	9.09	3.59	2.94	5.63	12.64	5.30	0.97	0.09	10.43	9.10	7.10	2.42	0.40	1.80	90.20
2002	1yrF2yrM	3	Histrtix	*M3*	1.32	0.65	0.49	5.60	41.85	5.30	1.00	0.07	14.93	2.20	3.40	2.50	0.28	1.45	84.36
2002	1yrF2yrM	4	Histrtix	*M3*	2.62	2.14	1.69	6.50	20.12	4.90	1.02	0.12	8.50	3.60	4.10	6.62	0.51	2.28	90.78
2002	1yrF2yrM	1	Natural	*M3*	6.91	4.74	3.86	4.50	16.02	4.80	0.55	0.10	5.29	5.20	5.80	7.40	0.28	1.28	87.26

2002	1yrF2yrM	2	Natural	*M3*	5.35	1.38	1.08	5.00	14.01	5.30	1.19	0.10	11.55	5.80	6.20	8.18	0.54	2.10	85.97
2002	1yrF2yrM	3	Natural	*M3*	2.28	1.46	1.17	6.67	35.54	5.30	0.62	0.05	11.92	2.70	3.40	5.98	0.49	1.80	88.77
2002	1yrF2yrM	4	Natural	*M3*	2.09	1.37	1.04	9.67	39.23	5.70	0.82	0.13	6.41	10.10	6.60	11.42	0.42	1.72	89.92
2002	1yrF2yrM	1	Soy	*M3*	5.40	3.91	3.13	0.26	15.85	4.90	0.75	0.09	8.62	5.20	3.80	1.87	0.32	1.88	91.78
2002	1yrF2yrM	2	Soy	*M3*	4.44	2.74	2.19	0.40	15.83	5.20	0.66	0.10	6.60	3.30	4.00	1.58	0.31	1.44	80.67
2002	1yrF2yrM	3	Soy	*M3*	7.09	4.06	3.28	0.38	25.18	5.30	0.69	0.06	12.11	7.30	3.80	1.88	0.24	1.38	93.00
2002	1yrF2yrM	4	Soy	*M3*	2.26	0.95	0.76	0.39	29.89	5.40	1.01	0.08	13.12	13.80	5.40	9.33	0.29	1.39	94.44
2002	1yrF2yrM	1	Stylo	*M3*	3.71	2.45	1.95	3.83	14.67	5.00	1.12	0.12	9.57	17.30	5.60	7.67	0.25	1.34	93.48
2002	1yrF2yrM	2	Stylo	*M3*	7.13	2.14	1.75	13.27	17.11	6.00	0.68	0.11	6.36	4.90	8.70	6.82	0.32	1.63	90.90
2002	1yrF2yrM	4	Stylo	*M3*	2.77	1.01	0.80	8.73	21.12	5.20	0.71	0.06	11.64	2.10	3.30	5.63	0.28	1.64	92.91
2002	1yrF2yrM	3	Stylo	*M3*	2.75	1.61	1.25	9.43	27.07	5.20	1.01	0.06	16.56	4.30	3.90	5.02	0.37	1.66	88.46
2002	2yrF1yrM	1	Centro	*M1*	5.10	2.96	2.43	3.17	36.39	5.00	1.26	0.09	14.82	5.20	4.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Centro	*M1*	8.68	4.04	3.36	6.00	34.49	5.70	0.78	0.09	8.48	17.40	6.10	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Centro	*M1*	5.16	1.87	1.49	4.00	39.05	5.10	0.61	0.08	7.35	4.00	4.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Centro	*M1*	1.86	0.91	0.73	9.33	13.77	5.40	0.88	0.08	11.58	9.00	4.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Cowpea	*M1*	3.33	2.65	2.11	1.32	17.31	4.90	0.63	0.10	6.56	6.60	4.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Cowpea	*M1*	5.95	2.85	2.31	2.04	13.00	5.30	0.59	0.08	7.20	6.30	4.60	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Cowpea	*M1*	2.69	1.70	1.34	1.08	88.44	5.30	0.66	0.06	11.00	9.40	4.90	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Cowpea	*M1*	3.86	2.17	1.76	1.11	36.32	5.00	0.55	0.08	7.05	5.60	6.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Gnut	*M1*	3.75	3.06	2.48	3.91	9.71	5.10	0.91	0.09	10.34	8.30	5.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Gnut	*M1*	7.64	3.71	3.04	1.68	12.02	5.50	0.74	0.11	6.85	10.60	5.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Gnut	*M1*	8.18	2.13	1.75	2.58	46.15	5.30	0.72	0.07	11.08	0.80	4.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Gnut	*M1*	4.35	2.56	2.12	3.27	29.13	5.10	0.40	0.08	5.33	4.80	4.10	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Histrtix	*M1*	7.70	4.76	3.87	3.53	14.13	5.00	1.00	0.09	10.75	6.00	2.80	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Histrtix	*M1*	6.87	3.29	2.70	7.40	17.87	5.40	0.47	0.11	4.35	8.40	6.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Histrtix	*M1*	2.52	0.99	0.77	3.27	61.34	5.00	0.76	0.11	7.10	2.30	5.00	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Histrtix	*M1*	5.25	1.70	1.31	4.67	51.93	4.90	0.66	0.09	7.67	9.60	4.00	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Natural	*M1*	4.33	3.42	2.77	3.17	46.13	5.00	1.02	0.10	10.52	5.00	3.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Natural	*M1*	5.46	2.72	2.26	6.33	40.60	5.40	1.02	0.12	8.29	5.50	9.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Natural	*M1*	2.73	0.64	0.49	5.83	28.09	5.30	1.01	0.06	18.04	12.40	5.60	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Natural	*M1*	2.69	1.09	0.85	8.00	39.16	5.20	0.61	0.06	9.68	2.80	3.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Soy	*M1*	7.30	3.33	2.72	0.33	31.74	5.20	0.72	0.08	8.78	3.60	4.60	0.00	0.00	0.00	0.00

2002	2yrF1yrM	2	Soy	*M1*	9.51	3.29	2.68	0.35	24.23	5.20	0.74	0.12	6.12	16.50	6.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Soy	*M1*	4.26	1.87	1.47	0.49	8.43	5.50	0.67	0.06	11.36	4.40	4.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Soy	*M1*	2.43	1.92	1.54	0.58	37.27	5.00	0.60	0.06	9.52	4.10	3.00	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Stylo	*M1*	5.48	3.30	2.66	4.33	11.94	5.20	0.69	0.12	6.00	7.50	6.10	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Stylo	*M1*	4.50	1.90	1.54	17.30	10.13	5.30	1.07	0.12	9.22	22.30	7.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Stylo	*M1*	2.35	1.90	1.50	7.47	31.84	5.40	0.85	0.06	14.17	8.60	6.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Stylo	*M1*	2.86	2.10	1.66	9.17	35.05	5.30	0.63	0.08	8.29	10.90	8.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Centro	*M2*	4.91	2.62	2.14	5.33	10.04	4.90	0.80	0.09	9.30	4.10	4.80	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Centro	*M2*	5.31	3.66	3.00	6.53	54.70	5.30	0.86	0.08	11.03	4.10	3.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Centro	*M2*	4.65	1.86	1.48	5.10	105.76	5.20	0.51	0.08	6.46	10.00	3.60	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Centro	*M2*	2.54	0.95	0.78	9.17	61.14	5.00	0.70	0.07	9.46	4.40	3.40	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Cowpea	*M2*	4.10	2.10	1.66	1.65	24.92	5.00	1.18	0.08	15.32	8.80	3.90	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Cowpea	*M2*	4.35	3.37	2.73	2.04	19.54	5.60	0.77	0.12	6.70	11.00	8.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Cowpea	*M2*	2.79	1.69	1.34	1.36	68.14	5.30	0.61	0.06	9.84	8.00	4.90	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Cowpea	*M2*	3.80	1.69	1.35	1.01	75.52	5.20	0.51	0.05	9.81	2.80	2.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Gnut	*M2*	4.03	3.32	2.70	6.31	20.94	5.20	0.91	0.11	8.35	20.00	6.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Gnut	*M2*	5.21	3.11	2.58	3.75	30.86	5.50	0.68	0.08	8.72	7.50	4.10	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Gnut	*M2*	3.99	2.88	2.38	4.25	43.36	5.20	0.74	0.07	10.00	3.50	3.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Gnut	*M2*	3.24	1.52	1.21	3.55	40.78	5.30	0.97	0.08	12.60	5.40	4.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Histrtix	*M2*	4.78	2.50	2.02	4.83	21.19	5.20	1.06	0.09	11.65	5.20	5.90	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Histrtix	*M2*	6.31	3.91	3.21	6.80	25.30	5.20	1.02	0.09	11.21	11.50	4.20	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Histrtix	*M2*	2.52	0.62	0.47	5.87	56.25	5.20	0.92	0.07	12.60	2.50	4.60	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Histrtix	*M2*	4.12	1.33	1.04	8.77	37.09	5.00	0.46	0.07	6.48	3.60	2.70	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Natural	*M2*	4.86	3.24	2.62	5.17	37.29	5.40	1.12	0.08	14.55	2.50	4.00	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Natural	*M2*	4.67	1.78	1.62	4.50	23.88	5.50	0.61	0.10	6.35	4.40	6.60	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Natural	*M2*	3.07	1.59	1.26	5.33	58.31	5.50	0.89	0.06	15.34	7.70	4.80	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Natural	*M2*	1.60	0.97	0.75	8.00	44.61	5.00	0.78	0.06	12.19	3.90	4.40	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Soy	*M2*	4.82	2.82	2.28	0.37	23.77	5.10	1.03	0.11	9.63	6.90	6.80	0.00	0.00	0.00	0.00
2002	2yrF1yrM	2	Soy	*M2*	7.25	3.42	2.83	0.69	16.76	5.30	0.78	0.11	7.16	12.90	5.40	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Soy	*M2*	4.44	3.12	2.72	0.49	16.05	5.50	0.56	0.08	7.00	10.90	6.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Soy	*M2*	2.84	1.25	0.97	0.46	43.35	5.30	0.96	0.06	16.55	4.80	3.40	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Stylo	*M2*	3.69	1.53	1.20	9.00	15.26	4.80	0.85	0.10	8.76	6.00	4.50	0.00	0.00	0.00	0.00

2002	2yrF1yrM	2	Stylo	*M2*	6.31	2.37	1.94	17.17	22.34	5.20	0.64	0.13	4.89	7.30	5.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	3	Stylo	*M2*	0.90	0.89	0.70	5.67	48.91	5.60	1.04	0.06	17.05	6.40	3.30	0.00	0.00	0.00	0.00
2002	2yrF1yrM	4	Stylo	*M2*	2.22	0.56	0.43	7.50	52.55	5.10	0.58	0.06	9.35	6.40	2.50	0.00	0.00	0.00	0.00
2002	2yrF1yrM	1	Centro	*M3*	6.74	3.72	3.03	4.17	25.09	5.70	1.34	0.12	10.81	6.20	7.50	2.83	0.58	2.38	89.47
2002	2yrF1yrM	2	Centro	*M3*	7.34	4.06	3.39	6.23	36.39	5.50	0.90	0.07	13.43	4.40	6.80	2.67	0.41	2.50	87.79
2002	2yrF1yrM	3	Centro	*M3*	2.05	1.21	0.96	2.50	51.11	5.20	1.14	0.09	13.41	12.10	3.80	7.35	0.35	1.48	89.90
2002	2yrF1yrM	4	Centro	*M3*	2.60	1.28	1.01	5.40	39.19	5.50	1.15	0.05	21.70	3.70	5.70	6.35	0.42	1.67	89.00
2002	2yrF1yrM	1	Cowpea	*M3*	3.78	3.32	2.76	2.13	26.16	5.00	1.08	0.08	13.50	4.20	4.50	2.58	0.22	2.09	90.43
2002	2yrF1yrM	2	Cowpea	*M3*	5.50	3.11	2.59	0.85	21.39	5.20	0.63	0.07	9.69	7.30	3.40	1.37	0.45	2.31	89.92
2002	2yrF1yrM	3	Cowpea	*M3*	4.27	1.88	1.52	0.74	48.18	5.40	1.58	0.06	25.08	4.60	4.30	1.22	0.28	1.51	89.21
2002	2yrF1yrM	4	Cowpea	*M3*	3.63	1.30	1.02	1.20	34.37	5.20	0.65	0.07	9.03	11.00	4.90	1.33	0.17	1.49	92.41
2002	2yrF1yrM	1	Gnut	*M3*	5.78	4.26	3.53	5.93	19.71	5.40	0.73	0.13	5.75	5.40	6.90	6.08	0.38	2.08	81.73
2002	2yrF1yrM	2	Gnut	*M3*	4.10	3.76	3.08	3.96	11.74	5.90	0.98	0.10	10.00	7.70	5.60	2.32	0.27	2.15	86.34
2002	2yrF1yrM	3	Gnut	*M3*	6.53	3.78	3.13	3.30	48.81	5.30	0.94	0.10	9.59	4.20	4.20	2.32	0.40	1.82	84.47
2002	2yrF1yrM	4	Gnut	*M3*	4.07	2.46	1.95	3.75	47.11	5.00	0.86	0.07	12.65	5.10	6.10	2.25	0.59	2.68	82.67
2002	2yrF1yrM	1	Histrtix	*M3*	5.78	3.22	2.63	2.67	21.10	5.20	0.97	0.07	13.11	5.90	3.00	3.50	0.50	2.01	89.26
2002	2yrF1yrM	2	Histrtix	*M3*	9.09	3.13	2.57	5.63	33.98	5.30	0.97	0.09	10.43	9.10	7.10	2.42	0.40	1.80	90.20
2002	2yrF1yrM	3	Histrtix	*M3*	1.60	1.27	0.97	5.60	61.70	5.30	1.00	0.07	14.93	2.20	3.40	2.50	0.28	1.45	84.36
2002	2yrF1yrM	4	Histrtix	*M3*	2.84	1.94	1.57	6.50	73.21	4.90	1.02	0.12	8.50	3.60	4.10	6.62	0.51	2.28	90.78
2002	2yrF1yrM	1	Natural	*M3*	5.76	3.11	2.57	4.50	29.52	4.80	0.55	0.10	5.29	5.20	5.80	7.40	0.28	1.28	87.26
2002	2yrF1yrM	2	Natural	*M3*	3.29	1.31	1.02	5.00	24.09	5.30	1.19	0.10	11.55	5.80	6.20	8.18	0.54	2.10	85.97
2002	2yrF1yrM	3	Natural	*M3*	5.02	1.04	0.80	6.67	48.87	5.30	0.62	0.05	11.92	2.70	3.40	5.98	0.49	1.80	88.77
2002	2yrF1yrM	4	Natural	*M3*	2.11	1.09	0.85	9.67	51.00	5.70	0.82	0.13	6.41	10.10	6.60	11.42	0.42	1.72	89.92
2002	2yrF1yrM	1	Soy	*M3*	6.25	2.72	2.22	0.26	22.05	4.90	0.75	0.09	8.62	5.20	3.80	1.87	0.32	1.88	91.78
2002	2yrF1yrM	2	Soy	*M3*	4.44	2.59	2.13	0.40	17.29	5.20	0.66	0.10	6.60	3.30	4.00	1.58	0.31	1.44	80.67
2002	2yrF1yrM	3	Soy	*M3*	4.58	2.58	2.05	0.38	28.44	5.30	0.69	0.06	12.11	7.30	3.80	1.88	0.24	1.38	93.00
2002	2yrF1yrM	4	Soy	*M3*	1.94	1.80	1.46	0.39	32.81	5.40	1.01	0.08	13.12	13.80	5.40	9.33	0.29	1.39	94.44
2002	2yrF1yrM	1	Stylo	*M3*	4.33	2.68	2.19	3.83	10.81	5.00	1.12	0.12	9.57	17.30	5.60	7.67	0.25	1.34	93.48
2002	2yrF1yrM	2	Stylo	*M3*	7.13	3.13	2.55	13.27	23.39	6.00	0.68	0.11	6.36	4.90	8.70	6.82	0.32	1.63	90.90
2002	2yrF1yrM	3	Stylo	*M3*	1.92	2.04	1.65	8.73	30.56	5.20	0.71	0.06	11.64	2.10	3.30	5.63	0.28	1.64	92.91
2002	2yrF1yrM	4	Stylo	*M3*	2.45	0.88	0.69	9.43	26.76	5.20	1.01	0.06	16.56	4.30	3.90	5.02	0.37	1.66	88.46

Appendix 11a Combine nutrient data for interactions analysis

Obs	Mplot	Rep	CompostP	CompostN	HLN	HLP	HLCP	WEDP	WEDCP	wtgainkg	wtgaingram	cropStov	cropCob	CropGrain
1	Centro	1	0.57649	2.37554	1.42139	0.12452	8.8553	0.10667	10.8194	0.95	19.388	4.1418	2.52485	1.85934
3	Centro	3	0.3527	1.48172	1.95039	0.15473	12.151	0.06333	4.5479	3.15	64.286	2.68819	1.22034	0.78773
4	Centro	4	0.41921	1.66608	2.6	0.181	16.198	0.06333	3.9457	2.35	47.959	1.95251	0.86435	0.55185
5	Cowpea	1	0.22363	2.08559	1.61266	0.1697	10.0469	0.09333	7.9744	2.5	119.048	3.39168	2.7829	1.97002
6	Cowpea	2	0.45	2.314	2.42102	0.15898	15.083	0.09333	5.4824	1.75	83.333	4.17575	2.50923	1.88019
7	Cowpea	3	0.28427	1.51211	1.61443	0.167	10.0579	0.05333	2.8658	2.5	119.048	2.43304	1.44069	0.9496
8	Cowpea	4	0.17245	1.48638	2.0859	0.17782	12.9952	0.06	3.5649	1.75	83.333	2.85114	1.26906	0.88682
9	Gnut	1	0.37997	2.08229	1.96564	0.13947	12.246	0.20667	11.9824	3.5	71.429	3.9409	3.30839	2.31657
10	Gnut	2	0.26818	2.15237	2.4373	0.19646	15.1844	0.21333	7.7044	5.25	107.143	4.87899	3.30596	2.36202
11	Gnut	3	0.39718	1.82195	2.73304	0.17933	17.0269	0.06	3.1358	1.75	125	3.37172	1.83669	1.26839
12	Gnut	4	0.59222	2.68198	2.68053	0.18339	16.6997	0.07333	3.2604	1.7	121.429	2.40783	1.24268	0.88697
13	Histrix	1	0.50415	2.00562	1.43953	0.18515	8.9683	0.13667	10.1134	1.2	85.714	4.31112	2.74395	2.06976
14	Histrix	2	0.39891	1.79579	2.09919	0.19176	13.078	0.13667	10.1134	2.05	146.429	5.777	3.25787	2.44981
15	Histrix	3	0.28332	1.45196	2.51559	0.18309	15.6721	0.13667	10.1134	1	71.429	1.90345	1.08035	0.57305
16	Histrix	4	0.50986	2.27898	2.03029	0.18898	12.6487	0.13667	10.1134	1.65	58.929	2.80778	1.38838	0.97094
17	Nat	1	0.28014	1.28446	1.83584	0.242	11.4373	0.08333	6.9776	1.3	46.429	4.34764	3.09112	2.34761
18	Nat	2	0.5417	2.10286	1.57774	0.19392	9.8293	0.08333	8.0782	0.9	42.857	4.47739	1.92817	1.34194
19	Nat	3	0.48773	1.79936	1.39534	0.17287	8.693	0.05667	3.2708	0.65	30.952	2.78272	1.33203	0.81606
20	Nat	4	0.42063	1.72308	1.36421	0.15899	8.4991	0.12	3.7588	-0.1	-4.762	2.1511	1.01274	0.64786
21	Soy	1	0.31795	1.88413	1.8461	0.17443	11.5012	0.17667	11.8993	3.1	88.571	5.3277	2.91072	2.14819
22	Soy	2	0.31195	1.43709	1.91039	0.16262	11.9017	0.08667	7.4552	2.25	64.286	5.97404	3.60015	2.64459
23	Soy	3	0.2375	1.37542	1.64865	0.1548	10.2711	0.08333	5.1294	2.3	65.714	4.17434	2.34799	1.66198
24	Soy	4	0.28579	1.39385	1.62455	0.14227	10.1209	0.06333	3.7588	4.8	85.714	1.89637	1.08965	0.7293
25	Stylo	1	0.25412	1.34445	2.00684	0.18311	12.5026	0.09333	10.4664	2.85	50.893	3.52509	3.05516	1.67869
26	Stylo	2	0.31643	1.62973	1.89281	0.18797	11.7922	0.14667	9.0024	1.9	33.929	5.0808	2.36039	1.75431
27	Stylo	3	0.27592	1.64326	1.84019	0.16997	11.4644	0.08333	7.3514	2.05	36.607	2.10735	1.60951	1.51666
28	Stylo	4	0.36757	1.65742	1.79587	0.19301	11.1883	0.07	6.7492	-0.1	-1.786	2.3949	1.15972	0.78078

Appendix 11a contds Combine nutrient data for interactions analysis.

Obs	Mplot	Rep	SOILpH	SOILC	SOILN	SOILCN	SOILP	SOILECEC	MZN	MZP	MZCP	WEDN
1	Centro	1	5.2	1.13333	0.09833	11.6441	5.1667	5.53333	1.78	0.216	11.0894	1.73667
2	Centro	2	5.5	0.84667	0.079	10.9789	8.6333	5.36667	2.16333	0.24633	13.4776	1.35
3	Centro	3	5.16667	0.75333	0.08233	9.0723	8.7	3.86667	2.06667	0.643	12.8753	0.73
4	Centro	4	5.3	0.91	0.06767	14.2455	5.7	4.53333	1.42	0.167	8.8466	0.63333
5	Cowpea	1	4.96667	0.96333	0.08433	11.7957	6.5333	4.23333	2.26667	0.12367	14.1213	1.28
6	Cowpea	2	5.36667	0.66333	0.08733	7.861	8.2	5.4	2.25333	0.21467	14.0383	0.88
7	Cowpea	3	5.33333	0.95	0.06167	15.306	7.3333	4.7	1.51333	0.18467	9.4281	0.46
8	Cowpea	4	5.13333	0.57	0.06733	8.6289	6.4667	4.53333	1.56667	0.17333	9.7603	0.57222
9	Gnut	1	5.23333	0.85	0.108	8.1459	11.2333	6.3	2.36667	0.311	14.7443	1.92333
10	Gnut	2	5.63333	0.8	0.09467	8.5233	8.6	5.06667	1.99667	0.321	12.4392	1.23667
11	Gnut	3	5.26667	0.8	0.079	10.2229	2.8333	3.93333	1.9	0.178	11.837	0.50333
12	Gnut	4	5.13333	0.74333	0.07333	10.1926	5.1	4.96667	1.76	0.20533	10.9648	0.52333
13	Histrix	1	5.13333	1.01	0.086	11.8364	5.7	3.9	1.59667	0.20033	9.9472	1.62333
14	Histrix	2	5.3	0.82	0.09733	8.6636	9.6667	5.93333	2.43667	0.27967	15.1804	1.62333
15	Histrix	3	5.16667	0.89333	0.08233	11.5436	2.3333	4.33333	1.46333	0.20167	9.1166	1.62333
16	Histrix	4	4.93333	0.71333	0.09233	7.5511	5.6	3.6	1.63333	0.165	10.1757	1.62333
17	Nat	1	5.06667	0.89667	0.09267	10.1165	4.2333	4.5	1.79667	0.19867	11.1932	1.12
18	Nat	2	5.4	0.94	0.10733	8.7334	5.2333	7.5	2.26667	0.17267	14.1213	1.29667
19	Nat	3	5.36667	0.84	0.05533	15.1012	7.6	4.6	1.54667	0.128	9.6357	0.525
20	Nat	4	5.3	0.73667	0.085	9.4254	5.6	4.73333	1.63	0.205	10.1549	0.60333
21	Soy	1	5.06667	0.83333	0.092	9.0091	5.2333	5.06667	1.9	0.19567	11.837	1.91
22	Soy	2	5.23333	0.72667	0.11	6.6239	10.9	5.36667	2.49	0.252	15.5127	1.19667
23	Soy	3	5.43333	0.64	0.06533	10.1537	7.5333	4.93333	1.91333	0.23133	11.9201	0.82333
24	Soy	4	5.23333	0.85667	0.066	13.0641	7.5667	3.93333	1.95333	0.218	12.1693	0.60333
25	Stylo	1	5	0.88667	0.10967	8.1118	10.2667	5.4	1.94667	0.22	12.1277	1.68
26	Stylo	2	5.5	0.79667	0.118	6.8216	11.5	7.3	1.92667	0.14667	12.0031	1.445
27	Stylo	3	5.4	0.86667	0.06067	14.2851	5.7	4.3	1.57	0.17367	9.7811	1.18
28	Stylo	4	5.2	0.74	0.06633	11.4006	7.2	4.86667	1.78667	0.196	11.1309	1.08333

Appendix 12 Procedures for soil analysis

Soil pH

This was determined with glass electrode pH meter (model PHM 82) in 1:1 soil to water ratio.

Determination of soil nitrogen

This was done by the vapodest/titrimetric method.

Reagents:

Kjeldahl catalyst tablets

Boric acid solution (20%)

Sodium hydroxide (NaOH) 1N

Sulphuric acid (H_2SO_4) 1N

Concentrated Sulfuric acid (H_2SO_4)

Distilled water

Buffer solution of pH 7 and pH 4

Analytical procedure:

2 g air-dried soil was measured (ground and passed through 0.5 mm sieve) into a set of 40 digestion tubes arranged in a metal rack. A tablet of Kjeldahl catalyst and 10 ml of concentrated sulphuric acid was added to the soil samples in each digestion tube. The soil samples were digested on a Tecator (model 3) soil digester at a temperature of 370 C for 2 hours in a fume chamber. At room temperature, 100 ml of distilled water was added to the digestion tubes. The

digestion tube containing the digest was transferred to the distillation unit (vapodest) containing boric acid and 1N sodium hydroxide.

Sodium hydroxide and a hot steam dispensed concurrently into the digest during distillation by pressing a button containing NaOH on the vapodest. Ammonia gas was released. The ammonium gas reacts with boric acid in the receiver unit of the vapodest to form ammonium borate.

At the end of the distillation process, 0.1N H_2SO_4 was dispensed automatically to the receiver chamber to neutralize the ammonium compound.

The volume (titre) of the 0.1N H_2SO_4 used to neutralize the ammonium compound was recorded from the TTT80 titrator attached to the vapodest. The titrator was standardized with buffer solution of pH 4 and pH 7, respectively with the end point set at 450. Percent total nitrogen in the soil was calculated as follows:

$\%TN = V \times 0.02 \times 14 \times 100/2 \times 1/100$

$\%TN = V \times 0.02 \times 7 \times 1000 \times 100$

where V is the volume of titrants used; 0.02 is the normality of sulphuric acid; 7/1000 is the equivalent weight of nitrogen in mg and 100 is the factor to change from decimal fractions to percentage.

Determination of organic carbon

The Walkley-Black method was used

Reagents:

Potassium dichromate ($K_2Cr_2O_7$) 1N. [49.04g of $K_2Cr_2O_7$ was dissolved in distilled water and diluted to 1 litre]

Concentrated sulphuric acid

Ferric sulphate ($FeSO_4$)

Buffer solution of pH 4 and pH7

Analytical procedure:

Soil samples were air-dried, ground and sieved through a 0.5 mm sieve.

1.0g soil was weighed out into a conical flask.

10 ml of 1N $K_2Cr_2O_7$ solution was dispensed into each flask. The flask was swirled to dispense the soil.

20ml of H_2S0_4 was added immediately into the soil suspension using an automatic laboratory dispenser. The conical flask was swirled vigorously for one minute in a fume-hood. The mixed soil solution was allowed to stand for 30 minutes. After this period, the suspension was diluted with 100 ml of distilled water. 1 ml of diphenylamine indicator was added and the flask swirled.

Two blank solutions were made in the same procedure but without soil. This was used to standardize the dichromate. The titrator was switched on and then standardized with the two buffer solutions of pH 4 and pH 7. The sample solutions were titrated against ferrous using TTT 80 alutric titrator to determine the amount of carbon in the sample.

The percentage organic carbon was calculated according to the following formula:

Milliequivalent of readily oxidizable material per gram of soil (me OX/g) = (ml Fe for blank – ml Fe for sample) x Normality of F

Weight of soil in (g)

b) Percentage organic carbon = me OX x 3/1000 x 100x 1.33

Where 3/1000 is the milliequivalent weight of carbon in g; 1.33 is the factor of converting the carbon actually oxidized to total carbon, and 100 is the factor to change from decimal fraction to percent.

Determination of exchangeable cations (K, Mg, Ca)

Reagents:

Extraction solution (this contains 1N ammonium acetate (NH4OAC) of pH7 and EDTA.

Reference standard –1000ppm

Stock standard –100 ppm

Working standard ranging from 0.2 ppm to 10.0 ppm

Analytical procedure:

5g of soil ground to pass a 2mm sieve were weighed into a set of 50 ml extraction cups. 50 ml of extraction solution (1N ammonium acetate, pH 7 and EDTA was dispensed to each extraction cup containing the weighed soil samples. The suspension was stirred for 15 minutes at 1500 revolutions per minute (rpm). The suspension was allowed to stand for 15 minutes and then filtered through Whitman No. 1 filter paper. Potassium was determined on a flame photometer.

Potassium (ppm) in solution was calculated from standard curves prepared from working standard.

Then

ppm (K) in soil = ppm cations solution x volume of extractant

weight of the soil in (g) me cation/100g soil

= ppm cation in soil 10 x meq. Weight of cations

= ppm cation in soil 10 x 291 meq.

(meq. Of the ions are given as Ca = 20mg; K = 39mg and Mg = 12mg).

Determination of available phosphorus

This was determined by Bray-1 method using Technicon autoanalyzer.

Reagents:

20 g of ammonium fluoride (NH_4F) was dissolved in 15 litre of distilled water.

36.4 ml of concentrated HCl was added to the NH_4F solution and diluted to 18 liters.

Ammonium molybdate antimonium titrate solution in 2.25 N H_2SO_4

Color reagent: 0.86 g of ascorbic acid was weighed into 100 ml of the ammonium molybdate antimonium titrate solution in a 100 ml volumetric flask and dissolved. This was diluted to one litre with distilled water.

Stock standard 'A' (2500 µg per ml): 15g of KH2PO4 was dissolved and made up to 1 litre with distilled water. Working stock standard 'B' in Bray 1 (250 µg per 1 liter: 25 ml of stock 'A' was pippetted into a clear 250 ml volumetric flask and made up to volume using Bray-1 extracting solution. This solution contains 250 µg per ml.

Working standard in Bray-1 (From stock 'B', 2.0, 4.0, 6.0, 8.0 and 10.0 ml were pipette into a clear 250ml volumetric flask. Each volumetric flask was made up to 250 ml mark with Bray-1 solution. The standard contained 2.0, 4.0, 6.0, 8.0 and 10.0 µg per ml respectively.

Analytical procedure:

5.0 g of air dried soil sieved through a 2 mm sieve was placed into the extraction cups. 30 ml of Bray-1 extraction solution was dispensed into each cup. The solution was stirred for 5 minutes on a mechanical stirrer. After stirring, the solution was allowed to stand for 2 minutes. This was filtered immediately into another set of extraction cups.

The filtered samples were transferred to the autoanalyzer cups. With the autoanalyzer chart reader set at zero, a baseline was established with all the reagents as follows. The autoanalyzer was operated on a steady state for 3 minutes using the 6 µg per ml standard. Chart reading was set at 60% chart division using a standard calibration of 3.0. The sample probe was returned to the wash cycle for 3 minutes and the zero baseline rechecked. The sample probe was allowed to aspirate the 6µg per ml standard 3 times. This was followed by the phosphorus standard of 2, 4, 6, 8 and 10µg per ml followed by 3 samples cups containing wash solution and then the unknown soil extracts.

µg in g soil =% chart reading x 0.1 µg per ml x 30.0 ml

Weight of soil in (g)

μg per ml is chart setting, 6 μg per ml is 60% chart division or 1% chart division = 0.1 μg per ml. 30 ml is volume of extraction solution.

Appendix 13. Model statement used for weed biomass calculation.

```
Proc sort data=T2;
  By sloc syear sside;
  Run;
Proc mixed data=T2;
 By  sloc syear sside;
 Class Rep mplot splot ;
 Model Weedyld=Mplot Splot Mplot*Splot /ddfm=satterth;
 Random Rep*Mplot;
 Lsmeans Mplot Splot Mplot*Splot ;
Run;
```

For weed seeds density, and weed species abundance calculations:

```
Proc sort data=T3;
 By syear loc stime Rep mplot splot;
Run;
Proc mixed data=T3;
 By  syear loc stime;
 Class Rep mplot splot;
 Model Tden=Mplot Splot Mplot*Splot/ddfm=satterth;
 Random Rep*Mplot;
 Lsmeans Mplot Splot Mplot*Splot;
Run;
Proc Univariate data=T2 noprint;
 Var denM2;
 By syear loc stime Rep Mplot splot;
 Output out = T3 Sum = TDEN;
 Run;
Proc sort data=T2;
  By syear loc stime mplot;
  Run;
 proc freq ; By syear loc stime mplot;
run;
```

where syear = sampling year, stime = sampling time, mplot= main plot treatment, weedyld = dry matter weed yield in Mg ha^{-1}, tden = total density, den*M2* = density m^{-2}. These variables were defined in the input statement of SAS.